EFFECTS OF DISTILLER'S DRIED GRAINS WITH SOLUBLES (DDGS) AND CORN GERM MEAL (CGM) ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF GROWING-FINISHING PIGS, AND DETERMINATION OF THE PRODUCTIVE ENERGY CONTENT OF DDGS AND CGM

BY

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THESIS

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ABSTRACT

A growth performance experiment was carried out over the grow-finish period to evaluate the effect of dietary inclusion level of Distillers Dried Grains with Solubles (DDGS) and Corn Germ meal (CGM) on growth performance and carcass characteristics. In addition, the results of the growth study were used to determine the Productive ME (PME) content of DDGS and CGM by correcting ME estimates for caloric efficiency relative to a control (reference) diet. The experiment was carried out as randomized complete block design (blocking factor was day of start of test) with a 4 × 2 factorial arrangement of treatments. There were 4 dietary treatments: 1.) Control- Corn-soybean meal, 2.) Dried Distiller's Grains with Solubles- 15% inclusion, 3.) Dried Distiller's Grains with Solubles- 30% inclusion, 4.) Corn Germ Meal- 20% inclusion and 2 sex treatments: barrows and gilts. A total of 3,072 pigs were allotted to 96 single-sex pens of 32 pigs to achieve 24 replicates per dietary treatment. The study was carried out from 10 weeks post- weaning (48.1 ± 3.18 kg) to approximately 22 weeks post- weaning (132.2 ±8.05 kg). A 4-phase dietary program was used, with diets being formulated within phase to be isocaloric (supplemental fat was used), and to a similar SID lysine to energy ratio. All diets were formulated to meet or exceed requirements proposed by the NRC (2012) for the weights of pigs used. The control (corn-soybean meal) was used as a reference diet to compare the DDGS and CGM diets with to estimate PME. Caloric efficiency was calculated for each treatment (from the feed:gain ratio). The ME value for DDGS used to formulate diets (3,003 kcal/kg) was based on published values and the ME value used for CGM (2,579 kcal/kg) was from Estrada (2017). The pen of pigs was the experimental unit; data were analyzed using PROC MIXED of SAS with the model including the fixed effect of dietary treatment and sex, random effect of block and replicate. Results indicated that there were no differences ($P > 0.05$) between dietary treatments for live weight at the end of test or overall average daily gain. The CGM treatment had lower ($P < 0.05$) average daily feed intake for the overall period than the other 3 treatments that were not different ($P > 0.05$) feed intakes. Overall gain:feed ratio was reduced ($P < 0.05$) for the DDGS 30% treatment than for the other 3 treatments. There was no effect ($P > 0.05$) of dietary treatment on carcass yield or backfat depth. *Longissimus* muscle depth was greater ($P < 0.05$) for the pigs on the Control treatment than the other 3 treatments. The PME estimated from the caloric efficiency (calculated from the feed:gain ratio) for DDGS 15%, DDGS 30%, and CGM were 98%, 91.9% and 108%, respectively of the original ME value used in diet formulation. These results suggest that inclusion of DDGS at 15% and CGM at 20% in diets for growing-finishing pigs had no negative impact on growth performance; however, including DDGS at a 30% of the diet had a negative effect on feed efficiency. There was considerable difference between PME estimates based on the growth study and the values originally used to formulate the experimental diets. In addition, the estimate of the PME of DDGS was considerably different between the two inclusion rates evaluated. Collectively, these results raise concerns about the variation found in PME estimates both between and within studies. Further research is required to understand the causes of this variation.

Key words: pigs, DDGS, CGM, productive energy

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CHAPTER 1: INTRODUCTION

Formulating swine diets is based on historical and current research on feed ingredients. A critical objective when formulating diets is to meet the requirements of the pig at different stages of production. In this regard, it is important to have accurate estimates of the available energy and nutrients in ingredients.

Swine diets in the US are mainly based on corn and soybean meal that are readily available and relatively inexpensive. In recent years, developments in the corn processing sector has resulted in an increasing quantity of corn co-products from the wet and dry milling industries becoming available for use in swine diets. The challenge to including these ingredients into swine diets that nutritionists face is the large variation in the composition of the co-products (Stein and Shurson, 2009; Anderson, 2012; Mendoza, 2013). In addition, there is relatively limited published information available on the composition of these ingredients that can be used to determine how to use these ingredients in swine diets. In particular, information is needed on the availability to the pig of energy and other nutrients that can be used to accurately formulate diets that maximize pig performance and lowest cost.

Distiller's Dried Grains with Solubles is a co-product from the ethanol industry that has a higher essential amino acid composition than corn (Stein and Shurson, 2009). A number of studies have evaluated the effects of dietary inclusion of DDGS on growth performance and carcass characteristics of pigs, and also on the energy content of DDGS. However, the composition of DDGS has changed over time as plants have become more efficient at, for example, removing the oil from this product. Therefore, there is a need to periodically evaluate this ingredient to understand how differences in composition affect animal performance.

Corn germ meal (CGM) is a co-product from the wet-milling industry that has a higher essential amino acid composition than corn (Almeida et al., 2011; Gutierrez et al., 2014). There is limited published research evaluating the effects of dietary inclusion of CGM on growth performance and carcass characteristics of pigs and on the energy content of CGM.

The research that is presented in this thesis was conducted with two main objectives: 1) determine the effects of including DDGS and CGM in the diet of growing-finishing pigs on growth performance and carcass characteristics; 2) determine the productive ME of DDGS and CGM based on the results of the growth performance assay.

LITERATURE CITED

Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 89:4109-4115.

Anderson, P. V., B. J. Kerr, T. E. Weber, C. J. Ziemer, and G. C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242-1254.

Gutierrez, N. A., N. V. L. Serão, B. J. Kerr, R. T. Zijlstra, and J. F. Patience. 2014. Relationships among dietary fiber components and the digestibility of energy, dietary fiber, and amino acids and energy content of nine corn coproducts fed to growing pigs. J. Anim. Sci. 92:4505-4517.

Mendoza, O. F. 2013. Development and validation of prediction equations for the metabolizable energy content of distillers dried grains with solubles from different sources for pigs. PhD Dissertation. University of Illinois at Urbana-Champaign.

Stein, H. H., and G. C. Shurson. 2009. Board-Invited review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

CHAPTER 2: LITERATURE REVIEW
ENERGY DIGESTIBILITY

Energy is generally defined as the capacity to perform or do work and can be classified as mechanical, molecular, electrical, or chemical in nature. In animal nutrition, energy is expressed in units as kilo-calories (kcal), mega-calories (Mcal) or joules (J) (NRC, 2012). The partitioning of feed energy as it is digested and metabolized by the animal is illustrated in Fig 2.1. Gross energy (GE) is the amount of energy produced when a compound is completely oxidized (NRC, 2012). To determine gross energy (GE), the feed is burnt and the heat produced is measured using a bomb calorimeter (NRC, 2012). Gross energy can be broken down into three subcategories: digestible energy (DE), metabolizable energy (ME), and net energy (NE). Digestible energy is defined as energy that may be used by the pig and can be calculated by the gross energy (GE) of the feed minus the heat of combustion of the fecal material (fecal energy) (Ewan, 2001). Metabolizable energy (ME) is DE minus the energy in urine and the energy in gases that are produced in the fermentation of diets in the digestive tract (urinary and gaseous energy) (NRC, 2012). Net energy is defined as ME minus heat increment energy (heat increment) (NRC, 2012). Net energy can be described in two forms; net energy for production and net energy for maintenance. Net energy for production is used for protein and fat synthesis, fetal development, and/or milk synthesis. Net energy for maintenance is used for maintenance of body temperature and normal bodily functions of the animal to sustain life. Another measurement of the energy content of a feedstuff is productive energy which will be discussed later in this chapter.

Research in these areas has allowed for a more precise estimation of these energy values that has increased the accuracy of formulating diets to maximize feed efficiency. Kil et al. (2013), in a review of the literature, discussed how there is a growing need to look into using ingredients and energy systems to be able to maximize the pigs' energy needs and not overfeed energy above requirements. Nyachoti et al. (2004) discussed how pigs will increase feed intake until they meet their energy requirements. More precise estimation of the energy content of feed ingredients will increase the accuracy of diet formulation and should decrease the amount of excess energy fed, decreasing the cost of diets.

Digestible Energy

Digestible energy (DE) is the energy that is digested and absorbed by the pig and can be calculated as the gross energy (GE) of the feed minus the heat of combustion of the fecal material (fecal energy) (Ewan, 2001). To determine DE, digestibility studies are conducted where pigs are housed in specially designed crates in a controlled environment, feed is controlled, and all feces are collected. The difference in the energy the pig consumed in feed and the energy excreted in the feces is the estimate of the DE content of the feed.

It is relatively easy to measure DE by collecting the feces and finding the difference in energy content between what was fed and what was excreted in the feces, however, there are some limitations to using this measurement. The principal issue is that the feces not only contain energy from the feed but also contains endogenous losses. Consequently, this measure of energy content is called apparent DE because it includes endogenous losses. Endogenous losses are any losses not from the diet fed such as, intestinal cells, enzymes, saliva, bile, etc.

Kil et al. (2013), in a review, discussed the variation of DE in complete diets for pigs and gave the range of DE being 70-90% of the GE in the diet. In a normal corn-soybean meal diet, DE represents on average around 82% of the GE in the diet fed to grow-finish pigs (Kil et al., 2013). Most of the variation in DE:GE ratio is the result of the type of ingredients that are included in the diet. For example, higher fiber or higher starch ingredients have much different DE:GE ratios because of the way the ingredients are digested and broken down. The inclusion of high fiber ingredients in the diet may decrease DE closer to 70% of GE in complete diets (Kil et al., 2013).

Although DE is relatively easy to measure, it is not the best method to use when formulating diets to meet pig's energy requirements because it does not take into account energy that is lost in urine, gases, or heat. Consequently, DE is ultimately not an accurate basis for estimating energy available to the animal for maintenance and/or production.

Metabolizable Energy

Metabolizable energy (ME) represents the energy that is available to the animal to use for maintenance and production and it is calculated by subtracting the energy in urine and gases from the DE content of the ingredient or feed. The gases are produced by the fermentation in the digestive tract; however, this energy loss is relatively small for conventional ingredients used in swine diets, generally less than 1% of DE. Studies have shown that there can be variation in the amount of gas loss from grow-finishing pigs, but it is normally very low. Noblet et al. (1994) suggested that gaseous losses are on average around 0.5% of DE. Consequently, gaseous energy losses are generally ignored in the estimation of ME (NRC, 2012).

To determine ME, metabolism studies are conducted where pigs are housed in specially designed crates in a controlled environment, feed is controlled, and all feces and urine are collected. The difference in the energy the pig consumed in the feed, and the energy excreted in the feces and urine is the estimate of the ME content of the feed.

In complete diets, energy loss in urine is relatively small with ME representing on average around 96% of DE with a range from 92 to 98% (NRC, 2012). However, as dietary protein levels increase the ratio of ME to DE will tend to decrease (Ewan, 2001).

Directly measuring the energy in urine involves using bomb calorimetry. Most of the energy lost in urine is in the form of nitrogen from the de-amination of excess protein within the animal. Consequently, the energy content of urine is commonly estimated by assaying the urinary nitrogen content (NRC 2012). This approach is generally accepted because nitrogen excretion is linked to crude protein content of a diet and the retention of protein by the pig (NRC, 2012). Therefore, ME:DE ratio is linearly related to protein content of a diet when determined in diets that have typical contents of crude protein (Noblet, 2005).

Metabolizable energy values are well established for feed ingredients and this is the most widely used basis for feed formulation in the US and worldwide (NRC, 2012). However, ME does not take into account energy lost as heat from the body (heat increment) that is produced during digestion and metabolism. Because of this, there is increased interest in moving to the use of NE systems for use in diet formulation. The NE of ingredients represents the energy available to the pig for maintenance and production (NRC 2012; Noblet, 2005).

Net Energy

Net energy (NE) is determined by subtracting the energy lost from the animal as heat (heat increment) from the ME content of the feed ingredient or feed (NRC, 2012). Heat increment is the energy that is lost from the animal from metabolism of nutrients and during tissue formation (Kil et al., 2010; Ewan, 2001). The NE can be divided further into net energy for production (NE_p), which is used for protein and fat synthesis, fetal development, and/or milk synthesis, and net energy for maintenance (NE_m), which is used for maintenance of body temperature and normal bodily functions to sustain life.

Net energy can be measured directly or indirectly. Direct measurement involves housing the animal in a calorimeter and measuring heat production (using respiration and convection calorimetry). Alternatively, NE can be determined through indirect calorimetry by measuring the oxygen used and the carbon dioxide and methane produced by the animal (Nienaber et al., 2009). Another approach to indirect measurement of NE is using the comparative slaughter method. This involves harvesting samples of pigs and determining their energy content at the start and end of a feeding period during which the test diets are fed. In theory, the difference in energy content of pigs at the start and end of the feeding period represents the energy that was utilized for growth, i.e., the NE for production.

These approaches have both advantages and disadvantages for measuring NE. Using a calorimeter for either direct or indirect measurement of NE limits activity levels because the pigs are confined to a small area. This potentially results in lower levels of heat produced for activity compared to the situation in commercial facilities where animals are housed in groups and activity levels would generally be greater (Kil et al., 2013). The comparative slaughter method allows for an accurate estimation of the body composition of the animal within an environment that is more comparative to the practical situation. However, different animals are used at the beginning and end of study to estimate the energy content. Consequently, this introduces some variation in the estimates of energy gain. Generally, these methods are expensive and time consuming and are practically difficult to carry out. In addition, ideally NE estimates should be validated using a growth assay that is conducted under practical conditions.

The relationship between ME and NE (ME:NE ratio) gives an estimate of the energy efficiency of converting ME to NE. This ratio varies according to the stage of production of the animal being fed, which influences what the energy is being utilized for (protein or fat deposition, fetal development, milk production) as well as factors such as the animal's activity level, and the environment that the animal experiences as well as the chemical composition of the feed (Noblet, 2007). Studies conducted by Noblet et al. (1994) determined that dietary fiber and protein have the lowest ratio of ME to NE (around 60%), with starch and fat having the highest ratio of ME to NE (around 82% and 90%, respectively). Normal efficiency for ME being converted to NE averages around 75% for conventional diets (Noblet, 2007).

In summary, measurement of NE is complex and expensive and must be carried out under very specific and controlled conditions. These include minimizing the physical activity of the animals and feeding balanced diets that ensure the animals have the potential to express their growth potential (Noblet, 2005). Consequently, it is not appropriate to measure NE of individual ingredients and this presents another major limitation for application.

Productive Energy

Productive ME (PME) represents the energy that the animal uses for growth. Interest in deriving productive energy estimates for feedstuffs has arisen because of concerns over the accuracy of using published values for DE, ME, or NE to formulate diets for pigs. This is particularly the case for ingredients that have not been widely evaluated, such as corn germ meal (CGM). Published estimates of the energy content of such ingredients are generally limited and can be variable. However, interest in the use of PME is relatively recent and there is limited published information relating to appropriate methodology to use for measurement of PME.

The determination of PME involves conducting a growth performance evaluation that uses a reference diet based on a standard major ingredient such as corn. The growth performance of pigs fed diets containing the test ingredient is compared with that of those fed the reference diet. In particular, the caloric efficiency of pigs on the test and reference diets is compared. Caloric efficiency is the number of calories consumed per unit of weight gain and is estimated using feed efficiency (feed:gain ratio) and the formulated energy content of the two diets being compared (Boyd et al., 2010; Boyd et al., 2011: Boyd et al., 2015). If there is a difference in caloric efficiency between the reference diet and the test diet, then that difference is assumed to be due to an inaccuracy in the estimate of the energy value for the test ingredient used in diet formulation. This difference in caloric efficiency is used to adjust the energy value of the test ingredient. The actual calculations and equations used to determine productive energy will be presented later in this review.

Boyd et al. (2015) carried out an experiment to determine the productive energy of choice white grease because published estimates of the energy content of this ingredient were not consistent. In this study, six different inclusion levels of fat were compared (0 (control), 1.90, 2.21, 2.58, 3.10, and 5.50%) in two 28 d growth assays that took place over two different growth periods: early (38 to 67 kg) and late finishing (79 to 107 kg), respectively. There was a difference among treatments for caloric efficiency, which was used to derive estimates of the productive NE of choice white grease for early and late finishing pigs (7,779 and 8,058 kcal/kg, respectively). These values were higher than those reported in NRC (2012). In another study, Boyd et al. (2010) determined the productive energy of wheat middlings using a growth assay which was carried out over a 26-day period between 79.5 and 109.2 kg live weight. The estimate of the productive energy of wheat middlings of 2,046 kcal/kg is lower than the ME of this ingredient reported by NRC (2012) of 2,113 kcal/kg; however, differences in energy value of this magnitude (-67 kcal/kg) are typical of those commonly that is normal when working with ingredients.

As previously discussed, measuring ME and, particularly, NE is costly and difficult. The productive energy method is a more simplistic, practical method to validate and adjust the ME or NE values of feed ingredients. There has been limited research carried out on productive energy and further research is needed to validate the approach and to understand the optimum conditions for measurement.

Equations to Predict the Energy Content of Feed Ingredients

Because the direct measurement of the energy content of feed ingredients is time consuming and expensive, there has been interest in developing equations for predicting the energy content of feed ingredients for use under commercial conditions. The starting point for these equations are studies that have directly measured the energy content of ingredients in vivo and have also analyzed the chemical composition of the ingredients. These data are used to develop regression equations that most accurately predict the energy content of the ingredient based on specific chemical components. In practice, samples of ingredients are analyzed for the content of the specific chemical components and the energy content to be used in diet formulation is estimated using the equation.

Equations to Predict Digestible Energy

Noblet and Perez (1993) developed prediction equations for DE based on the chemical composition of a feed ingredient or complete diet. These equations are published in NRC (2012) and are as follows:

$$DE(kcal/kg) = 1{,}161 + (0.749 \times GE) - (4.3 \times Ash) - (4.1 \times NDF) \ \ \boldsymbol{Eq.\ 2.1}$$

$$DE(kcal/kg) = 4{,}168 - (9.1 \times Ash) + (1.9 \times CP) + (3.9 \times EE) - (3.6 \times NDF) \ \ \boldsymbol{Eq. 2.2}$$

The chemical components are expressed as g/kg of DM.

Equations to Predict Metabolizable Energy

One approach to predicting ME content is to use a predicted ME:DE ratio to adjust the predicted DE content. Le Goff et al. (2001) developed an equation to determine the ME:DE ratio based on the digestible crude protein (CP) content of the ingredient as follows:

$$ME/DE = 100.3 - (0.021\ X\ CP, g/kg) \ \ \boldsymbol{Eq.\ 2.3}$$

Noblet and Perez (1993) developed equations that more accurately predicted the ME content based on the chemical composition of ingredients. The equations are as follows:

$$ME(Kacl/kg\ DM) = 4{,}194 - (9.2\ \times Ash) + (1.0\ X\ CP) + (4.1 \times EE) - (3.5 \times NDF) \ \ \boldsymbol{Eq.\ 2.4}$$

$$ME(Kcal/kg\ DM) = (1.00 \times DE) - (0.68 \times CP) \ \ \boldsymbol{Eq.\ 2.5}$$

The chemical components are expressed as g/kg of DM.

Equations to Predict Net Energy

Noblet et al. (1993; 1994a) developed equations to predict NE based on either DE or ME values in combination with chemical composition. The equations below are presented in the NRC (2012) (all nutrients are expressed as g/kg of DM):

$$NE(Kcal/kg\ DM) = (0.726\ \times ME) + (1.33 \times EE) + (0.39 \times Starch) - (0.62 \times CP) - (0.83 \times ADF)\ \textbf{\textit{Eq.}}\ \mathbf{2.6}$$

$$NE(Kcal/kgDM) = (0.700 \times DE) + (1.61 \times EE) + (0.48 \times Starch) - (0.91 \times CP) - (0.87 \times ADF)\ \textbf{\textit{Eq.}}\ \mathbf{2.7}$$

These equations were developed using complete diets and not using individual ingredients, and, consequently, research is still needed to develop equations to predict the NE of individual ingredients (NRC, 2012).

Although using these equations is a relatively simple approach to the prediction of energy content of an ingredient for use in diet formulation, there are a number of factors that can affect the accuracy of these equations. This includes factors such as the amount and form of the fiber, and the chemical composition of the ingredients or diets, and whether these equations were developed using individual ingredients or complete diets.

USE OF DISTILLER'S DRIED GRAINS WITH SOLUBLES IN SWINE DIETS

The US ethanol industry has developed rapidly over the last few decades and currently has the potential to produce 22 million metric tons of Distiller's Dried Grains with Solubles (DDGS). Approximately half of this is exported with exports in 2017/2018 being 11 million metric tons (U.S. Grain Council, 2019). The major objective of the corn dry grind industry is to produce ethanol. The process to produce ethanol is outlined in RFA (2014). This process involves grinding the corn kernel and mixing with water to create a mash to which enzymes are added. The mash is heated to a high temperature and transferred to a fermentation tank where yeast is added. Following fermentation, distillation columns are used to separate the ethanol from the stillage. The stillage is sent through a centrifuge where wet grains and thin stillage are separated. The thin stillage is condensed into syrup and the wet grains are dried in a ring dryer or drum dryer; this dried product is called dried distiller's grains (DDG). Syrup is sold as a separate product or added back into the (DDG) to create the DDGS.

Composition of Distiller's Dried Grains with Solubles

A summary of published values for the composition of distiller's dried grains with solubles is presented in Table 2.1. These values were obtained from 7 published sources. Distiller's dried grains with solubles is considered a fibrous ingredient with a crude fiber (CF) content ranging from 6.9% to 10% and neutral detergent fiber (NDF) ranging from 27.6 to 51.0%. It contains between 3.2 and 11.7% fat and 30.2 to 34.7% crude protein. The content of essential amino acids is generally higher for DDGS than for corn; however, amino acid digestibility is generally lower for DDGS than corn (Stein and Shurson, 2009).

Effects of Distiller's Dried Grains with Solubles on Growth Performance

A summary of 17 studies investigating the effects of dietary DDGS inclusion on the growth performance of grow-finish pigs is presented in Table 2.2.

Nine of the studies showed no effect of including DDGS at up to 20% of the diet on ADG. However, 7 studies found that including 10 to 30% DDGS in the diet of grow-finish pigs resulted in a linear reduction in ADG. Fifteen of the studies showed there was no effect of including DDGS in the diets from 0 to 30% on average daily feed intake (ADFI) or gain: feed ratio (G:F). One study by Xu et al. (2010) did find that ADFI was reduced and G:F was increased linearly when dietary DDGS level was increased from 0 to 30%.

A review by Stein and Shurson (2009) summarized the results from 25 studies and concluded that including DDGS in diets at up to 20% did not affect growth performance (ADG, ADFI, or G:F). However, some studies showed that at higher inclusion levels of 30% DDGS or greater in the diets can have a negative effect on growth performance. Some studies have shown no effect on ADG or ADFI but a decrease in G:F when diets containing DDGS at inclusion levels greater than 30% were fed. Stein and Shurson (2009) concluded that the difference in results relating to the effect of DDGS on growth performance may be due to variation in the energy supplied by the DDGS.

In conclusion, studies have shown that including up to 20% DDGS in diets for grow-finish pigs will have little effect on growth performance. However, higher inclusion levels have been shown to have negative effects on the growth performance of growing-finishing pigs in some studies.

Effects of Distiller's Dried Grains with Solubles on Carcass Characteristics

A summary of studies investigating the effects of dietary DDGS inclusion on carcass characteristics of harvest weight pigs is presented in Table 2.2. There were 15 studies investigating the effects on carcass yield and backfat, 13 studies investigating the effect on *Longissimus* muscle depth and 2 studies investigating the effect on hot carcass weight.

Two studies showed no effect of dietary DDGS inclusion level on hot carcass weight. In addition, 14 studies showed no effect of including DDGS from 10 to 30% of the diet on backfat depth. For carcass yield, 9 out of fifteen studies showed no effect of DDGS inclusion, however, 6 studies found that including DDGS in the diet reduced carcass yield when DDGS was included at 30 to 40%. Eleven out of 13 studies showed no effect of feeding DDGS on *Longissimus* muscle depth, whereas 2 studies showed a decrease in this measure in pigs fed diets including up to 30% DDGS.

Stein and Shurson (2009), in a review of the literature, concluded that the greatest effect of including DDGS in diets is on carcass yield. They reviewed 18 studies that measured carcass yield and 10 of those showed no effect, however, 8 of the studies showed there was a decrease in carcass yield in pigs fed DDGS. They concluded that due to the high fiber content of DDGS the effect on carcass yield could be due to a larger intestinal fill compared to those grow-finish pigs that were not fed the DDGS diets. These authors also reported limited effects of feeding DDGS on backfat depth and *Longissimus* muscle depth. In studies that did show an effect of feeding DDGS on *Longissimus* muscle depth, Stein and Shurson (2009) suggested that this was the result of a reduced ADG for the pigs fed DDGS which resulted in the animals being slaughtered at a lower body weight leading to a decrease in *Longissimus* muscle depth.

In conclusion, the published literature would suggest that feeding diets with up to 30% DDGS inclusion can result in a reduction in carcass yield but has little effect on other carcass measures.

Energy Content of Distiller's Dried Grains with Solubles

Mendoza (2013) reviewed published estimates of the energy content of DDGS and the results of this review, which was based on 14 published studies, are summarized in Table 2.3. The gross energy content (as fed basis, kcal/kg) of the 66 samples that were evaluated in these studies ranged from 4,972 to 5,712, the DE content ranged from 3,100 to 4,140, and the ME content ranged from 2,858 to 3,897 ME (Mendoza, 2013). One factor that can contribute to the variation in published values of the energy content of different DDGS sources is the measuring technique that was used to measure GE, DE, and ME (Stein and Shurson 2009; Mendoza, 2013). Different methods for measuring energy values could lead to higher or lower values. One example is using in vivo or in vitro digestibility studies. The amount of the ingredient that is used in these two approaches is considerably different and this is one factor that is responsible for very weak relationship between the digestibility values determined by these two approaches (Graham et al., 1989).

This variation in energy values, as illustrated in Table 2.3, causes difficulty when deciding on the appropriate value to use for formulating diets that have high inclusion rates of DDGS. The use of prediction equations that use the chemical composition of DDGS can help to more accurately predict the energy content of DDGS and the equations presented by NRC (2012) are often used in this regard. However, these equations were developed by Noblet and Perez (1993) using mixed diets and, therefore, are not specific to individual ingredients. More recent studies have attempted to develop equations specifically to predict the ME content of DDGS (e.g., US Grain Council, 2012).

Another problem with the use of equations to predict ME content of ingredients based on chemical composition is the large variation that is observed between analytical laboratories in the chemical composition of the samples of the same ingredient from the same source (AFIA, 2007). This can, obviously, lead to large variation in the energy value used in diet formulation which can have a large economic impact. It is important when using these predictions equations to use the same laboratory for all ingredient analysis to decrease variation in predicted energy values.

Another potential source in the variation in the composition of DDGS is variation in the composition of sample of the corn that was used to produce the ethanol and the DDGS. Belyea et al. (2004) evaluated the relationship between the composition of the corn sample used in fermentation and the composition of the resultant DDGS and found that the correlations were weak. This suggests that a significant part of the variation in the composition of DDGS originates during the process of producing ethanol and DDGS. There is evidence of significant differences in the composition of DDGS from different ethanol plants (Belyea et al., 2010).

In conclusion, there is considerable variation in the composition of DDGS samples that are available for feeding to pigs due mainly to differences between plants in processing conditions. One approach to take variation in energy content of DDGS samples into account is to have each batch of DDGS analyzed for chemical composition and to use these values in equations to predict, for example, the ME content of the DDGS. Given the between-laboratory variation in chemical composition values obtained from the analysis of the same batches of ingredients, it is important to use a single laboratory for all analyses.

USE OF CORN GERM MEAL IN SWINE DIETS

The US corn wet milling industry is not as diverse and as large as the dry grind sector. In 2018, the corn germ meal production in the U.S. was reported as 61,021 tons (USDA, 2019). The major objective of the corn wet milling industry is to produce pure starch and corn oil. The process to produce starch is outlined in RFA (2014); the process involves soaking the kernel in water to easily separate the kernel into smaller, basic components. After the kernel is soaked, it is processed through grinders to separate the corn germ. Once the germ is separated from the other components the oil is extracted from the germ (either at the plant or the germ is sold, and oil extracted at another facility). Once the oil is extracted the remaining corn germ is known as corn germ meal (CGM).

Composition of Corn Germ Meal

A summary of published values for the composition of CGM is presented in Table 2.4. These values were obtained from 6 published sources and 2 unpublished studies. Corn germ meal is considered a high fiber ingredient with a crude fiber (CF) content ranging from 7.52 to 10.69% and neutral detergent fiber (NDF) ranging from 36.99 to 61.05% on a as fed and DM basis, respectively (Anderson et al., 2012; Estrada, 2015). It contains less than 2% fat and 21% to 25% crude protein. The content of essential amino acids is higher than corn; however, amino acid digestibility is generally lower for CGM than corn (Almeida et al., 2011 and Gutierrez et al., 2014).

Effects of Corn Germ Meal on Growth Performance

There has been relatively limited research evaluating the use of CGM in diets for pigs. A summary of 3 studies investigating the effects of dietary CGM inclusion on the growth performance of nursery and grow-finish pigs is presented in Table 2.5. The CGM inclusion levels used in these studies ranged from 12.5 to 50%.

These studies showed no effect of including CGM at up to 40% of the diet on average daily feed intake; however, Jones (1987) showed an increase in average daily feed intake in pigs fed diets with 50% compared to 0% CGM. Jones (1987) and Weber et al. (2010) showed no effects of including up to 25% CGM in the diet on average daily gain. However, Jones (1987) and Weber et al. (2010) found a decrease in average daily gain when CGM was included at levels above 25% up to 50% in the diet. Similarly, Estrada (2017) found that including CGM in diets from 10 to 30% resulted in no effect on average daily gain but at 40% inclusion in the diets average daily gain was reduced. Jones (1987) and Estrada (2017) found a linear decrease in G:F with increasing CGM inclusion up to 50% and 40%, respectively. However, Weber et al. (2010) showed a quadratic relationship between CGM inclusion level and G:F with pigs fed diets with 12.5% and 25% inclusion having poorer feed efficiency than those fed diets with lower (0%) or higher levels (30%).

In conclusion, studies show that including CGM in diets for growing pigs at levels greater than 40% decreased growth rate and feed efficiency, with little or no effect on feed intake. Consequently, these studies generally also showed a negative effect of CGM inclusion on feed efficiency. One potential reason for these results could be inaccurate estimates of the energy content of CGM.

Effects of Corn Germ Meal on Carcass Characteristics

A summary of studies investigating the effects of dietary CGM inclusion on the carcass characteristics of harvest weight pigs is presented in Table 2.5. There were 2 studies that investigated the effects of dietary inclusion level of CGM on hot carcass weight, carcass yield and backfat depth.

Both studies showed effects on hot carcass weight and carcass yield in response to increasing dietary inclusion of CGM. Estrada (2017), in a large-scale study, showed a linear reduction in hot carcass weight (-1.7 kg) and carcass yield (-2.8 percentage units) with increasing dietary inclusion levels of CGM from 0 to 40%. Jones (1987) also found a reduction in hot carcass weight and carcass yield at CGM inclusion levels of 25 to 50% in the diet.

Estrada (2017) found no effect on backfat depth of including up to 40% CGM in the diet. However, Jones (1987) found that pigs that were fed diets with CGM at 50% inclusion had decreased backfat depth. The difference in the results between these two studies could be associated with the lighter harvest weights (~5kg) of pigs that were fed diets that had 50% CGM inclusion in the study of Jones (1987) compared to pigs that were fed 0 to 40% in the study of Estrada (2017).

In conclusion, studies show that feeding diets that included CGM at greater than 25% inclusion rate reduced carcass yield and hot carcass weight, with no clear effects on other carcass traits (Table 2.5). The most likely explanation for the negative effect of feeding CGM on carcass yield is the high fiber content of this ingredient leading to enlargement of the intestines and increased gut fill (Jones, 1987; Pond et al., 1988).

Energy Content of Corn Germ Meal

A summary of published values for the energy content of CGM is presented in Table 2.6. There are relatively few published values for the energy content of CGM and, also, high variation between the published values. Estimates of the gross energy content (as fed basis kcal/kg) ranged from 4,178 to 4,330, estimates of the DE content ranged from 2,740 to 3,103, and estimates of the ME content ranged from 2,630 to 3,011 (Table 2.6). This variability between the estimates of the energy content could result from a number of factors including differences in the methodology used to measure the energy or differences between the samples used in the studies (Stein and Shurson, 2009; Mendoza, 2013).

Estrada (2017) determined the productive energy content of CGM using a growth assay with pigs from weaning to harvest weight (7 to 127 kg). The study included a corn-soy diet and two CGM diets with inclusion rates 12.5 and 25%, respectively. The ME values used to formulate the diets for corn and CGM were those given by NRC (2012) and Anderson et al. (2012), respectively. These ME values were adjusted based on the analyzed chemical composition of the batches of ingredients used in the study. Estrada (2017) found that feed:gain ratio increased linearly with increasing dietary inclusion of CGM. As a result of this increase in feed:gain ratio in pigs fed the CGM diets, the estimated productive ME of CGM (average of the values for the 2 CGM diets) was 2,604 kcal/kg, which was significantly lower (432 kcal), than previously reported ME values.

Estrada (2017) conducted a second study to validate the results from the first study. In the second study, a corn-soy diet and 4 diets with a range of CGM inclusion levels (10, 20, 30, 40%) were compared. The ME value of CGM used to formulate diets was that estimated in the previous study conducted by Estrada (2017). The results of the second study showed a linear increase in feed:gain ratio with increasing CGM inclusion. The productive ME that was determined in the study (by averaging the productive energy of the diets with the three lowest CGM levels) was 2,483 kcal/kg. This value was 211 kcal lower than that found in the first study.

In conclusion, published estimates of the energy content of CGM show large variation. Estimates of the productive energy of CGM derived from growth assays have generally given values that are lower than published values of the ME content of this ingredient. However, estimates of the productive ME of CGM also show substantial variation suggesting that further research is needed to validate the use of productive energy determination as a practical approach for ingredient evaluation.

FIGURE AND TABLES

Fig. 2.1 Flow of Energy

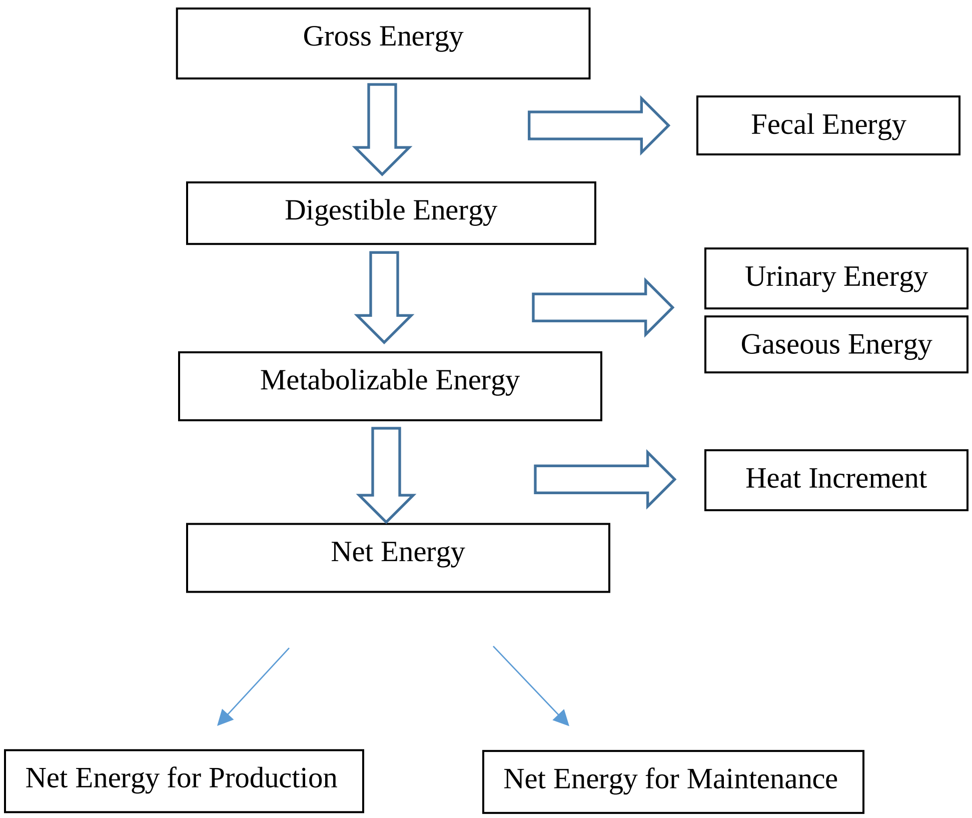

Table 2.1. Summary of the chemical composition of distillers dried grains with solubles previously reported.[1]

Publication	No. of Samples	DM, %	CP, %	Starch, %	Crude fat, %	ADF, %	NDF, %	Ash, %	Crude fiber, %
Spiehs et al., 2002	118	88.9	30.2	-	10.9	16.2	42.1	5.8	8.8
Stein et al., 2006	10	88.9	30.9	7.3	-	12.2	45.2	-	-
Pedersen et al., 2007	10	87.6	32.2	8.2	11.7	11.6	27.6	4.4	-
Anderson et al., 2012	1	87.4	34.7	3.0	3.2	15.8	51.0	5.2	8.7
Anderson et al., 2012	6	89.1	31.3	4.3	11.4	12.1	40.4	4.45	7.8
Kerr and Shurson, 2013	14	87.6	30.5	2.2	9.7	11.7	38.9	5.1	-
NRC, 2012, > 10% oil	12-81	89.3	30.6	7.5	11.7	13.2	36.4	4.6	7.9
NRC, 2012, > 6 and < 9% oil	4-13	89.4	30.3	10.8	10.0	13.5	34.1	4.5	10.0
NRC, 2012, < 4% oil	1-2	89.3	31.2	11.2	4.0	19.0	37.8	5.2	6.9

[1]Values are expressed on 100% DM basis.

Table 2.2 Effects of including corn distillers dried grains with solubles in diets fed to growing-finish pigs.[1]

		Response to dietary corn DDGS, No. of experiments		
Item	n[2]	Increase	Decrease	No Change
ADG	17	1	7	9
ADFI	17	1	1	15
G:F	17	1	1	15
Hot carcass weight	2	0	0	2
Carcass yield	15	0	6	9
Backfat	15	0	1	14
Loin Depth	13	0	2	11

[1]Data from experiments by: Gralapp et al. (2002), Fu et al. (2004), Cook et al. (2005), DeDecker et al. (2005), McEwen (2006), Whitney et al. (2006c), Gowans et al. (2007), Hinson et al. (2007), Jenkin et al. (2007), White et al. (2007), Widyartne and Zijlstra (2007), Drescher et al. (2008), Duttlinger et al. (2008), Linneen et al. (2008), Stender and Honeyman (2008), Weimer et al. (2008), Widmer et al. (2008), Xu et al. (2007a).
[2]Total number of experiments used.

Table 2.3. Summary of published estimates for GE, DE, and ME (kcal/kg DM) and digestibility (%) of DM and energy of corn distillers dried grains with solubles and corn (Mendoza, 2013).

Publication	Samples	DDGS			Corn			DDGS Relative to NRC (2012) corn (%)	
		GE	DE	ME	GE	DE	ME	DE	ME
Widyaratne and Zijlstra, 2007	1	-	3,900	-	-	-	-	99.8	-
Pedersen et al., 2007[4]	10	5,434	4,140	3,897	4,496	4,088	3,989	105.9	101.4
Feoli, 2008[1]	2	5,193	3,680	-	4,483	3,818	-	94.2	-
Stein et al., 2009[4]	4	5,593	4,072	3,750	-	4,181	4,103	104.2	97.6
Dahlen et al., 2011[4]	1	-	3,351	2,964	-	-	-	85.7	77.1
Dahlen et al., 2011[2,4]	1	-	3,232	2,959	-	-	-	82.7	77.0
Jacela et al., 2011[3,4]	1	5,098	3,100	2,858	-	-	-	79.3	74.3
Anderson et al., 2012[4,5]	1	5,076	3,868	3,650	-	-	-	99.0	95.0
Anderson et al., 2012[4]	6	5,420	4,029	3,790	-	-	-	103.1	98.6
Liu et al., 2012[4]	3	5,423	3,982	3,730	5,022	3,682	3,577	99.6	97.0
NRC, 2012, > 10% oil	16	5,429	4,053	3,845	4,454	3,908	3,844	103.7	100.0
NRC, 2012, > 6 and < 9% oil	3	5,271	4,009	3,801	-	-	-	102.6	98.9
NRC, 2012, < 4% oil	2	5,712	3,687	3,476	-	-	-	94.3	90.4
Kerr and Shurson, 2013[4]	15	4,972	3,664	3,444	-	-	-	94.5	90.1

[1]ME was determined using the index method.
[2]Low-soluble DDGS.
[3]DDGS sample was subject to oil extraction prior to energy determination; DE measure via a digestibility experiment; ME was calculated using an equation from Noblet and Perez (1993) using the DE measured value.
[4]Energy concentration measured using standard experiments in which the apparent DE and ME are measured by difference.
[5]DDGS sample was subject to oil extraction prior to energy determination.

Table 2.4. Estimates of the nutrient composition of corn germ meal.

Publication	No. of Samples	DM, %	CP, %	Starch, %	Crude fat, %	ADF, %	NDF, %	Ash, %	Crude fiber, %
Weber et al., 2010[1]	1	-	21.07	14.20	2.12	11.13	54.41	2.41	9.53
Almeida et al., 2011	1	89.41	24.76	15.93	-	11.30	49.29	-	-
Anderson et al., 2012[2]	NR	89.13	23.64	10.47	-	12.49	61.05	2.70	10.69
NRC, 2012[1]	2	90.10	23.33	14.20	-	10.75	44.46	2.96	9.53
Estrada, 2014[1,3]	13	88.27	23.84	-	-	12.05	37.27	2.59	7.56
Gutierrez et al., 2014[1]	1	91.90	20.60	16.40	-	11.50	46.20	-	-
Rojas et al., 2014[1]	1	89.41	24.76	-	-	11.30	49.29	5.47	-
Estrada, 2015[1,3]	7	88.56	23.69	-	-	11.21	36.99	2.77	7.52

NR=Data was not reported.
[1]As-fed basis.

[2]Dry matter basis.
[3]Unpublished data.

Table 2.5. Effects of including corn germ meal in diets fed to pigs.[1]

		Response to dietary corn DDGS, No. of experiments		
Item	n[2]	Increase	Decrease	No Change
ADG	3	0	2	1
ADFI	3	0	0	3
G:F	3	0	3	0
Hot carcass weight	2	0	2	0
Carcass yield	2	0	2	0
Backfat	2	0	1	1
Loin Depth	2	0	1	1

[1]Data from experiments by: Jones, 1987; Weber et al., 2010; Estrada, 2017.

[2]Total number of experiments used.

Table 2.6. Summary of published estimates for GE, DE, and ME (kcal/kg DM) of DM and energy of corn germ meal and corn.

		Corn Germ Meal			Corn			CGM Relative to NRC (2012) corn (%)	
Publication	Samples	GE	DE	ME	GE	DE	ME	DE	ME
NRC, 2012	-	4,178	2,988	2,830	3,933	3,451	3,395	-	-
Anderson et al., 2012[1]	1	4,201	3,103	3,011	3,799	3,456	3,387	89.9	88.7
Gutierrez et al., 2014[2]	1	4,330	2,740	2,630	-	-	-	79.4	77.5
Rojas et al., 2014[1]	1	4,184	3,073	2,817	3,924	3,498	3,375	89.0	83.0

[1]Energy concentration was measured using standard experiments in which the apparent DE and ME are measured by difference in GE content.

[2]DE value was determined by multiplying the GE by the observed ATTD of GE of the ingredient, and the ME was estimated from the calculated DE and CP of the ingredient (Noblet and Perez, 1993).

LITERATURE CITED

Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 89:4109-4115.

AFIA. 2007. Evaluation of analytical methods for analysis of distillers grains with solubles. AFIA sub-working group final report and recommendations. https://poet.com/resources/research/dakotagold/other/DDGS%20Analytical%20Methods%20-%202007.pdf. (Accessed April 3, 2019).

Anderson, P. V., B. J. Kerr, T. E. Weber, C. J. Ziemer, and G. C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242–1254.

Belyea, R. L., K. D. Rausch, M. E. Tumbleson. 2004. Composition of corn and sitillers dried grains with solubles from dry frind ethanol processing. Bioresource Technology. 94:293-298.

Belyea, R.L., K. D. Rausch, T. E. Clevenger, V. Singh, D. B. Johnston, and M. E. Tumbleson. 2010. Sources of variation in composition of DDGS. Anim. Feed Sci. Technol. 159:122–130.

Boyd, R. D., C. E. Zier-Rush, and C. E. Fralick. 2010. Practical method for estimating productive energy (NE) of wheat midds for growing pigs. J. Anim. Sci. (Abstr.). 2010 in press.

Boyd, R. D., C. E. Zier-Rush, and C. E. Fralick. 2011. Practical method for productive energy (NEm+g) estimation of soybean meal for growing pigs. J Anim Sci. (Abstr.). 2011 in press.

Boyd, R. D., C. E. Zier-Rush, M. McGrath, R. Palan, J. Picou, and E. van Heugten. 2015. Calibration of net energy for fat by growth assay in early and late phases of growth in pigs. J. Anim. Sci (Abstr.). 2015 in press.

Cook, D., N. Paton, and M. Gibson 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. J. Anim. Sci. 83(Suppl. 1):335. (Abstr.).

DeDecker, J. M., M. Ellis, B. F. Wolter, J. Spencer, D. M. Webel, C. R. Bertelsen, and B. A. Peterson. 2005. Effects of dietary level of distiller dried grains with solubles and fat on the growth performance of growing pigs. J. Anim. Sci. 83(Suppl. 2):79. (Abstr.).

Drescher, A. J., L. J. Johnston, G. C. Shurson, and J. Goihl. 2008. Use of 20% dried distillers grains with solubles (DDGS) and high amounts of synthetic amino acids to replace soybean meal in grower-finisher swine diets. J. Anim. Sci. 86(Suppl. 2):28. (Abstr.).

Duttlinger, A. W., M. D. Tokach, S. S. Dritz, J. M. DeRouchy, J. L. Goodband, R. D. Goodband, and H. J. Prusa. 2008. Effects of increasing dietary glycerol and dried distillers grains with solubles on growth performance of finishing pigs. J. Anim. Sci. 86(Suppl. 1):607. (Abstr.).

Estrada, J. R. 2017. Effects of body weight and research conditions on the productive energy content of corn germ meal fed to growing-finishing pigs. PhD Diss. Univerity of Illinois, Urbana-Champaign.

Ewan, R. C. 2001. Energy utilization in swine nutrition. In: A. J. Lewis and L. L. Southern, editors, Swine Nutrition. 2nd ed., CRC Press, New York, NY. p. 85–94.

Fu, S. X., M. Johnston, R. W. Fent, D. C. Kendall, J. L. Usry, R. D. Boyd, and G. L. Allee. 2004. Effect of corn distiller's dried grains with solubles (DDGS) on growth, carcass characteristics, and fecal volume in growing finishing pigs. J. Anim. Sci. 82(Suppl. 2):80. (Abstr.).

Gowans, J., M. Callahan, A. Yusupov, N. Campbell, and M. Young. 2007. Determination of the impact of feeding increasing levels of corn dried distillers grains on performance of growing-finishing pigs reared under commercial conditions. Adv. Pork Prod. 18:A-22. (Abstr.).

Gralapp, A. K., W. J. Powers, M. A. Faust, and D. S. Bundy. 2002. Effects of dietary ingredients on manure characteristics and odorous emissions from swine. J. Anim. Sci. 80:1512–1519.

Graham, H., W. Löwgren, Åman, Per. (1989). An in vitro method for studying digestion in the pig. 2. Comparison with in vivo ileal and faecal digestibilities. The British journal of nutrition. 61. 689-98.

Grieshop, C. M., D. E. Reese, and G. F. Fahey. 2001. Nonstarch polysaccharides and oligosaccharides in swine nutrition. In: A. J. Lewis and L. L. Southern, editors, Swine Nutrition. 2nd ed., CRC Press, New York, NY. p. 107-130.

Gutierrez, N. A., N. V. L. Serão, B. J. Kerr, R. T. Zijlstra, and J. F. Patience. 2014. Relationships among dietary fiber components and the digestibility of energy, dietary fiber, and amino acids and energy content of nine corn coproducts fed to growing pigs. J. Anim. Sci. 92:4505-4517.

Hinson, R., G. Allee, G. Grinstead, B. Corrigan, and J. Less. 2007. Effect of amino acid program (Low vs. High) and dried distiller's grains with solubles (DDGS) on finishing pig performance and carcass characteristics. J. Anim. Sci. 85(Suppl. 1):437. (Abstr.).

Jenkin, S., S. Carter, J. Bundy, M. Lachmann, J. Hancock, and N. Cole. 2007. Determination of P-bioavailability in corn and sorghum distillers dried grains with solubles for growing pigs. J. Anim. Sci. 85(Suppl. 2):113. (Abstr.).

Jones, R. W. 1987. Corn co-products as feed ingredients for swine: Effects on growth, carcass composition and fiber and amino acid digestibility. PhD Diss. Univerity of Illinois, Urbana-Champaign.

Kerr, B. J., and G. C. Shurson. 2013. Effects of DDGS nutrient composition (reduced-oil) on digestible and metabolizable energy value and prediction in growing pigs. Agricultural Utilization Research Institute. http://www.auri.org/assets/2013/01/ Effects-of-DDGSNutrient-Composition-Reduced-Oil-on-Digestible-and-Metabolizable-Energy-Value-andPrediction-in-Growing-Pigs.pdf. (Accessed April 3, 2019).

Kil, D. Y., B. G. Kim, and H. H. Stein. 2013. Invited review: Feed energy evaluation for growing pigs. Asian-Australas. J. Anim. Sci. 26:1205-1217.

Le Goff, G., and J. Noblet. 2001. Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. J. Anim. Sci. 79:2418-2427.

Linneen, S. K., J. M. DeRouchy, S. S. Dritz, R. D. Goodband, M. D. Tokach, and J. L. Nelssen. 2008. Effects of dried distillers grains with solubles on growing and finishing pig performance in a commercial environment. J. Anim. Sci. 86:1579–1587.

McEwen, P. L. 2006. The effects of distillers dried grains with solubles inclusion rate and gender on pig growth performance. Can. J. Anim. Sci. 86:594. (Abstr.).

Mendoza, Omarh. 2013. Development and valdiation of prediction equations for the metabolizable energy content of distillers dried grains with solubles from different sources for pigs. PhD Diss. Univerity of Illinois, Urbana-Champaign.

Nienaber, J. A, J. A. DeShazer, H. Xin, P. E. Hillman, J. T. Yen, and C. F. Ferrell. 2009. Measuring energetics of biological processes. In: J. A. DeShazer, editor, Livestock energetics and thermal envornmental management. American Society of Agricultural and Biological Engineers, St. Joseph, MI. p. 73-112.

Noblet, J. 2007. Net energy evaluation of feeds and determination of net energy requirements for pigs. R. Bras. Zootec. 36 (suppl.):277-284.

Noblet, J. 2005. Recent advances in energy evaluation of feeds for pigs. In: P.C. Garnsworthy and J. Wiseman, editors, Recent advances in animal nutrition. Nottingham University Press, Nottingham, UK. p. 1-26.

Noblet, J., and J. van Milgen. 2004. Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J. Anim. Sci. 82 (E. Suppl.):E229-E238.

Noblet, J., and X. S. Shi. 1994. Effect of body weight on digestive utilization of energy and nutrients of ingredients and diets in pigs. Livest. Prod. Sci. 37:323-338.

Noblet, J., H. Fortune, X. S. Shi, and S. Dubois. 1994a. Prediction of net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

Noblet, J, X. S. Shi, and S. Dubois. 1994b. Effect of body weight on net energy value of feeds for growing pigs. J. Anim. Sci. 72:344-354.

Noblet, J., and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. 71:3389-3398.

Noblet, J., and X. S. Shi. 1993. Comparative digestibility of energy and nutrients in growing pigs fed ad libitum and adult sows fed at maintenance. Livest. Prod. Sci. 34:137-152.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Nyachoti, C. M., R. T. Zijlstra, C. F. M. de Lange, and J. F. Patience. 2004. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. Can. J. Anim. Sci. 84:549-566.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168–1176.

PIC. 2016. Pig Improvement Company. Subject: Nutrient Specifications Manual 2016. http://na.picgenus.com/sites/genuspic_com/Uploads/files/Nutrition/English%20Imperial_2016%20Nutrient%20Specifications%20Manual_9-7-16.pdf. (Accessed 2 March 2019).

Pond, W. G., H. G. Jung, and V. H. Varel. 1988. Effect of dietary fiber on young adult genetically lean, obese and contemporary pigs: Body weight, carcass measurements, organ weights and digesta content. J. Anim. Sci. 66:699-706.

RFA. 2014. Renewable Fuels Association. Subject: Ethanol Industry Statistics 2013. Renewable Fuels Assoc., Washington, DC. http://www.ethanolrfa.org/wp-content/uploads/2015/09/9864ff506e6519057b_t5m6brouu.pdf. (Accessed 7 March 2019).

Rojas, O. J, Y. Liu, and H. H. Stein. 2014. Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 91:5326-5335.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639–2645.

Stein, H. H., and G. C. Shurson. 2009. Board-Invited Review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Stein, H. H., C. Pedersen, M. L. Gibson, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles by growing pigs. J. Anim. Sci. 84:853–860.

Stender, D., and M. S. Honeyman. 2008. Feeding pelleted DDGS-based diets to finishing pigs in deep-bedded hoop barns. J. Anim. Sci. 86(Suppl. 2):50. (Abstr.).

Urriola, P. E., G. C. Shurson, and H. H. Stein. 2010. Digestibility of dietary fiber in distillers coproducts fed to growing pigs. J. Anim. Sci. 88:2373-2381.

U.S. Grain Council. 2019. Buying-Selling DDGS. 2019 Production and Exports. U.S. Grain Council, Washington, DC. https://grains.org/buying-selling/ddgs/. (Accessed 7 March 2019).

U.S. Grain Council. 2012. A Guide to Distiller's Dried Grains with Solubles (DDGS). 3rd Edition. U.S. Grain Council, Washington, DC. https://www.canr.msu.edu/uploads/236/58572/cfans_asset_417244.pdf. (Accessed 19 April 2019).

USDA. 2019. Grain Crushings and Co-Products Production. 2018 Summary. National Agricultural Statistics Service, Washington, DC. https://www.nass.usda.gov/Publications/Todays_Reports/reports/cagcan17.pdf. (Accessed 7 March 2019).

Weber, T. E., S. L. Trabue, C. J. Ziemer, and B. J. Kerr. 2010. Evaluation of elevated dietary corn fiber from corn germ meal in growing female pigs. J. Anim. Sci. 88:192-201.

Weimer, D., J. Stevens, A. Schinckel, M. Latour, and B. Richert. 2008. Effects of feeding increasing levels of distillers dried grains with solubles to grow-finish pigs on growth performance and carcass quality. J. Anim. Sci. 86(Suppl. 2):51. (Abstr.).

White, H., B. Richert, S. Radcliffe, A. Schinckel, and M. Latour. 2007. Distillers dried grains decreases bacon lean and increases fat iodine values (IV) and the ratio of n-6:n-3 but conjugated linoleic acids partially recovers fat quality. J. Anim. Sci. 85(Suppl. 2):78. (Abstr.).

Whitney, M. H., G. C. Shurson, L. J. Johnson, D. M. Wulf, and B. C. Shanks. 2006c. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. J. Anim. Sci. 84:3356–3363.

Widmer M. R., L. M. McGinnis, D. M. Wulf, and H. H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork. J. Anim. Sci. 86:1819-1831.

Widyaratne, G. P., and R. T. Zijlstra. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growth performance of grower-finisher pigs. Can. J. Anim. Sci. 87:103–114.

Xu G., S. K. Baidoo, L. J. Johnston, D. Bibus, J. E. Cannon, and G. C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with solubles to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1398-1410.

CHAPTER 3: EFFECTS OF DISTILLER'S DRIED GRAINS WITH SOLUBLES (DDGS) AND CORN GERM MEAL (CGM) ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF GROWING-FINISHING PIGS, AND DETERMINATION OF THE PRODUCTIVE ENERGY CONTENT OF DDGS AND CGM

INTRODUCTION

Formulating swine diets is based on historical and current research on feed ingredients. A critical objective when formulating diets is to meet the requirements of the pig at different stages of production. In this regard, it is important to have accurate estimates of the available energy and nutrients in ingredients.

Swine diets in the US are mainly based on corn and soybean meal that are readily available and relatively inexpensive. In recent years developments in the corn processing sector has resulted in an increasing quantity of corn co-products from the wet and dry milling industries becoming available for use in swine diets. The challenge to including these ingredients into swine diets that nutritionists face is the large variation in the composition of the co-products (Stein and Shurson, 2009; Anderson, 2012; Mendoza, 2013). In addition, there is relatively limited published information available on the composition of these ingredients that can be used to determine how to use these ingredients in swine diets. In particular, information is needed on the availability to the pig of energy and other nutrients that can be used to accurately formulate diets that maximize pig performance and lowest cost.

Distiller's Dried Grains with Solubles (DDGS) is a co-product from the ethanol industry that has a higher essential amino acid composition to that of corn (Stein and Shurson, 2009). There has been many studies and values published evaluating the effects of dietary inclusion of DDGS on the growth performance and carcass characteristics (Table 2.2) of pigs and the energy content (Table 2.3) of DDGS. Even though there has been studies looking at the effects and energy content of DDGS, each ethanol plant has different procedures for drying and producing DDGS; therefore, when looking at a new source it is important to evaluate the product and the effects it may have on growth performance due to the composition.

Corn germ meal (CGM) is a co-product from the wet-milling industry that has a higher essential amino acid composition than corn (Almeida et al., 2011; Gutierrez et al., 2014). There is limited published research evaluating the effects of dietary inclusion of CGM on the growth performance and carcass characteristics of pigs (Table 2.5) and on the energy content (Table 2.6) of CGM.

Therefore, a study was conducted with two main objectives: 1) determine the effects of including DDGS and CGM in the diet of growing-finishing pigs on growth performance and carcass characteristics; 2) determine the Productive ME (PME) of DDGS and CGM based on the results of the growth performance assay.

MATERIALS AND METHODS

The experiment was conducted between September 2018 and December 2018 at the Maschhoffs' Georgia Technology Center, a standard commercial wean-to-finish facility that is located near New Minden, IL. The experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC#18188).

Experimental Design and Treatments

The experiment was carried out as a randomized complete block design (blocking factor was day of start of test) with a 4 × 2 factorial arrangement of treatments. There were 4 dietary inclusion treatments; Treatment 1) Control- Corn-soybean meal, 2) Dried Distillers' Grains with Solubles - 15% inclusion- (DDGS-15%), 3) Dried Distillers' Grains with Solubles -30%

inclusion- (DDGS 30%), 4) Corn Germ Meal (CGM) - 20% inclusion and 2 sex treatments; barrows and gilts.

Diets were formulated to be isocaloric and meet or exceed the nutrient requirements of pigs across the weight range used in this study recommended by the NRC (2012). Diets were formulated to the same standardized ileal digestible (SID) lysine and ME levels (9.44, 7.58, 6.88, 9.48 g/kg in the 4 dietary phases used, respectively), with fat (yellow grease) being added to achieve this. The DDGS used for this experiment was obtained from a single source (Center Ethanol Co. LLC, Sauget, IL) and the CGM was obtained from a single source (Archer Daniels Midland, Decatur, IL). The analyzed composition of the major ingredients used in the diets are presented in Table 3.2. The Lys:CP ratio for the samples of SBM, DDGS, and CGM used in the study were 5.83, 2.47, and 3.60, respectively. The ratio for CGM is in line with ratios commonly seen with this ingredient. However, the ratios for SBM and DDGS are lower than expected for these ingredients. A possible cause of these lower ratios heat damage during the processing of the SBM and DDGS samples. The analyzed composition of diets used in each phase of the 4 treatment diets are present in Tables 3.3 to 3.6.

The ME values used in diet formulation for the corn, DDGS and CGM were 3,380, 3,003 and 2,579 kcal/kg, respectively. These are the ME values from NRC (2012) and Estrada (2017) adjusted for analyzed chemical composition for each ingredient. The CGM diet was formulated to the same NDF level as the DDGS-30% treatment.

Diets were manufactured at the Carlyle Mill of The Maschhoffs in pellet form (diameter- 3.18mm). A 4-phase dietary program was used with the amount of each phase being according to the feed budget shown in Table 3.1.

Animals and Allotment

This experiment used the progeny of a commercial sire line mated to the same commercial crossbred dam line. The study was carried out from 10 weeks post- weaning (48.1 ±3.18 kg) to approximately 22 weeks post-weaning (132.2 ±8.05 kg).

A total of 3,072 pigs were allotted to 96 single-sex pens of 32 pigs to achieve 24 replicates per diet composition treatment. A replicate consisted of 8 pens; 4 pens of each sex. Outcome groups of 4 pigs of the same sex and body weight were selected and within outcome group one pig was randomly allotted to each of the 4 pens. This process was repeated until there were 32 pigs of the same sex (barrow or gilt) in each pen. The 4 pens of the same sex in the replicate were weighed as a group and pigs were exchanged between pens to obtain a similar weight (± 0.68 kg) across pens. Pens were randomly allotted to dietary treatment and started on test.

Housing

Pigs were housed in 2 rooms of a wean-to-finish building with the capacity to hold 1,800 pigs per room. The rooms had fully slatted, concrete floors and were tunnel ventilated. Each pen was equipped with a box type feeder and two cup-type water drinkers. The feeder space was the same for both types of feeders (4.45 cm per pig). Feed and water were available *ad libitum* throughout the study period. The thermostat controlling the temperature in each of the rooms was set at 18°C for the duration of the study. Temperature in the rooms was maintained using heaters and fan ventilation.

The floor space was 0.67m^2/pig for all treatments. In the case of a pig being removed during the study period for mortality or morbidity, pen size was adjusted using a moveable gate at the back of the pen to keep a constant floor space per pig throughout the study.

Growth Performance Measurements

Group pen weights were recorded at the beginning of the experiment and every 2 weeks thereafter for calculation of average daily gain (ADG). An electronic, computerized feed system (BigFarmNet, Big Dutchman Inc., Holland, MI) was used to deliver and record the amount of feed dispensed to the feeder in each pen. The amount of feed in the feeder was measured every time that the pigs were weighed. Total feed delivered to each pen and feed remaining in the feeder were used to calculate average daily feed intake and gain:feed.

Pigs that died, and morbid animals, not responding to treatment were removed from the study and the weight and date of removal were recorded. These were used in the calculation of average daily feed intake and average daily gain based on the number of days that the pigs were on test before they were removed from the study.

Harvest and Carcass Measurements

Pens were taken off test in two groups (heaviest 50% first and lightest 50% second). When the pen mean weight reached 107.6 ± 2.2 kg, the feeding of the final dietary phase which included Ractopmaine (10ppm) started. Two weeks after the start of feeding Ractopamine the heaviest 50% of the pigs in pen were weighed as a group and sent for harvest. Two weeks after that the remaining 50% of the pigs in the pen were weighed as a group and sent for harvest. Pigs were transported to the JBS USA plant in Beardstown, IL on a standard transport trailer (with 160 pigs/load). Pigs were held in lairage for at least 2 hours prior to slaughter, which was carried out using standard procedures. Carcass grading measurements were taken on the slaughter line including hot carcass weight and Fat-O-Meter® for backfat thickness and *Longissimus* (loin) muscle depth. These measurements were then used to estimate a predicted carcass lean content.

Productive Metabolizable Energy Calculations

The following calculations were used to estimate the Productive ME (PME) of DDGS and CGM (all concentrations are expressed on an as-fed basis):

1) ***Caloric Efficiency*** (CE) of each dietary treatment was obtained by multiplying the feed: gain ratio by the formulated ME content of the diet:

$$CE\ (kcal/kg\ of\ gain) = Feed{:}Gain\ \times (Formulated\ ME_{Diet}\ kcal/kg) \quad \mathbf{Eq.\ 3.1}$$

2) To be able to calculate a ***Corrected ME*** content of the test diets (diets that included DDGS and CGM), the Formulated ME content of the test diet was multiplied by the Caloric Efficiency of the control diet divided by the Caloric Efficiency of the test diet:

$$Corrected\ ME_{Test\ diet}\ (kcal/kg) = Formulated\ ME_{Test\ diet}\ \times \left(\frac{CE_{Control\ diet}}{CE_{Test\ diet}}\right) \quad \mathbf{Eq.\ 3.2}$$

3) The ***ME Difference of the Test Diet*** (difference between Formulated and Corrected ME content) was obtained by subtraction:

$$ME\ Difference_{Test\ diet} = Formulated\ ME_{Test\ diet} - Corrected\ ME_{Test\ diet} \quad \mathbf{Eq.\ 3.3}$$

4) The ME Difference of the Test Diet is assumed to be completely due to a discrepancy in the ME value of the Test Ingredient used in formulation. The ***ME Difference of the Test Ingredient*** was calculated by dividing the ME Difference of the test diet by the proportion of the test ingredient included.

$$ME\ Difference_{Test\ ingredient}\ (kcal/kg)$$

$$= ME\ difference_{Test\ diet,}\ kcal/kg$$

$$\div Test\ Ingredient\ inclusion \quad \textbf{Eq. 3.4}$$

5) ***Productive ME*** was obtained by subtracting the Energy Difference of the test ingredient from the Formulated Energy of the test ingredient:

$$Productive\ Energy\ (kcal/kg)$$

$$= Formulated\ ME_{\ Test\ ingredient} - ME\ Difference_{Test\ ingredient} \quad \textbf{Eq. 3.5}$$

Statistical Analysis

All data were tested for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC.). All data met the requirements for analysis of variance and were analyzed using the PROC MIXED procedure of SAS as a randomized complete block design with pen as the experimental unit. The model included the fixed effect of dietary ingredient treatment, sex, and the interaction and the random effect of replicate (which accounted for room and day of start of test effects). Least-squares means were compared using the PDIFF option of SAS. Morbidity and mortality data were not normally distributed and were analyzed using a Chi-Square test, with pig being the experimental unit.

RESULTS AND DISCUSSION

The effects of DDGS and CGM inclusion level on growth performance and carcass characteristics are summarized in Tables 3.7 and 3.8, respectively. There were no interactions between sex and dietary treatment and the effects of sex were similar to those found in other studies; therefore, only the main effects of dietary treatment are presented.

Effects of DDGS and CGM inclusion level on growth performance

Live weights at the start of test and at the end of Week 2 were not different ($P > 0.05$) for the treatments; however, the pigs fed the DDGS 30% treatment were lighter ($P < 0.05$) than the other 3 treatments at the end of Week 4 and 6 (Table 3.7). In addition, average daily gain for Start to Week 2 and Week 2 to Week 4 was lower ($P < 0.05$) for the pigs fed the DDGS 30% treatment than the pigs fed the Control and DDGS 15% treatments. However, there were no treatment effects ($P > 0.05$) on any of the other interim live weights or interim average daily gain or on final live weight at the end of test, overall average daily gain, and days on test. These results were similar to those of most studies that have evaluated the effect of dietary inclusion of DDGS on growth performance (Table 2.2). Most studies have found no effect on growth performance of including DDGS at up to 20% of the diet. However, a number of studies showed a reduction in ADG when DDGS was included at greater than 20% of the diet (Table 2.2). Stein and Shurson (2009), in a review of the literature on the effects of feeding normal oil DDGS, concluded that published results on the effects of feeding diets with more than 30% DDGS on growth performance were variable.

Average daily feed intake was greater ($P < 0.05$) for the pigs fed the Control and DDGS 15% treatments than for the CGM treatment from Start to Week 2 and Week 2 to Week 4, with the DDGS 30% treatment being not different ($P > 0.05$) to the other 3 treatments during these interim growth periods. During Week 6 to Week 8 and for the overall study period, pigs fed the CGM treatment had a lower ($P < 0.05$) average daily feed intake than the other 3 treatments, which had feed intakes that were not different ($P > 0.05$) (Table 3.7). These results were different from results of Jones (1987), Weber et al. (2010) and Estrada (2017; Table 2.5) that showed no effect of including CGM in diets on average daily feed intake.

There were treatment differences ($P < 0.05$) for gain:feed ratio for several of the interim growth periods and for the overall growth period (Table 3.7). In general, pigs fed the CGM treatment had the highest and the DDGS 30% had the lowest gain:feed ratio; however, differences among treatments were not different for all of the interim growth periods (Table 3.7). Stein and Shurson (2009), in a review of the literature, concluded that several studies have shown that the effect of feeding DDGS on growth performance was often greater for feed efficiency than for growth rate and feed intake, which is similar to the results of the present study. Stein and Shurson (2009) suggested that this effect was due to variation in the energy supplied by the DDGS.

In the current study, pigs fed the CGM treatment had the highest feed efficiency of all the dietary treatments evaluated, including the corn-soybean control diet, a finding which is different from that of other studies. Jones (1987) and Estrada (2017) both showed a linear decrease in G:F as CGM dietary inclusion level increased from 0% to 40%. A possible explanation is that the CGM samples used in the current study may have had a higher energy value than the value used to formulate the diets, resulting in a higher feed efficiency for the CGM treatment than the other treatments.

There were treatment differences ($P < 0.05$) for carcass average daily gain and carcass gain:feed ratio with pigs fed the DDGS 30% having the lowest carcass daily gain and lowest carcass feed efficiency and the other three treatments not being different (Table 3.7). Few, if any, studies have included these measurements in results. Given that, in most situations, pigs are valued on the basis of carcass weight rather than live weight then it is important to include these measurements in any evaluation.

In conclusion, there were no differences between the treatments for overall growth rate; however, overall feed efficiency was greater for pigs fed the CGM treatment than the other 3 treatments and was greater for pigs fed the Control and DDGS 15% than the DDGS 30%. Including DDGS at 30% during the grow-finish period can reduce growth performance.

Effects of DDGS and CGM inclusion level on carcass characteristics

Pigs on the DDGS 30% and CGM treatments had lower ($P < 0.05$) hot carcass weight than those on the Control and DDGS 15% treatments (Table 3.8). However, this difference was in part due to numerical, not different ($P > 0.05$) treatment differences in harvest live weight as there were no treatment differences ($P > 0.05$) in carcass yield. Most studies have shown that feeding DDGS has no effect on carcass yield (Table 2.2) at inclusion levels below 30%, which is similar to the results of the current study. However, most studies have shown a linear decrease in carcass yield with increasing CGM inclusion level, which is different than the results of the current study. Generally speaking, increasing the level of inclusion in the diet of ingredients with high fiber content is expected to have a negative effect on carcass yield due to factors such as increased gut contents. In the present study, there was no effect of diet on carcass yield, however, all the treatments that included either CGM or DDGS had lower carcass yield than the corn-soybean meal control treatment, although none of these differences were different ($P > 0.05$).

Backfat depth did not differ ($P > 0.05$) among treatments. This result was similar to the results of most other studies that have investigated the effect of feeding CGM or DDGS to growing pigs (Tables 2.2 and 2.5). *Longissimus* muscle depth was greater ($P < 0.05$) for the Control than the other treatments, however, the differences among treatments were relatively small. This was similar to results of most other studies (Table 2.2) that showed no effects of including DDGS or CGM (Table 2.2 and 2.5) in the diet on *Longissimus* muscle depth.

In conclusion, the dietary treatments evaluated in this study had relatively small effects on carcass measurements.

Estimation of the Productive Metabolizable Energy of DDGS and CGM

The steps in calculating PME are summarized in Table 3.9. The starting point is the results for feed:gain ratio for the different dietary treatments, which were presented in Table 3.7 and have been discussed previously. The first step was to calculate the Caloric Efficiency of the diets used in the study test diets, which is obtained by multiplying the feed:gain ratio by the formulated ME content of the diet. Caloric Efficiency values were greatest for the DDGS 30% diet and lowest for the CGM diet, with the Control and DDGS 15% diets having intermediate and relatively similar values for Caloric Efficiency (Table 3.9). As the formulated ME of the 4 diets was the same, differences among the 4 diets in Caloric Efficiency reflect the original differences in feed:gain ratio.

The next step was to calculate a Corrected Energy level for the test diets, which was estimated by multiplying the formulated ME content of the test diet by the ratio between the caloric efficiencies of the control and test diet (Table 3.9). The assumption in this step was that the ME of corn and soybean meal was well established and that the value used in diet formulation was accurate. Therefore, any difference between the control and the test diet for Caloric Efficiency must be due to an error in the ME value of the test ingredient that was used in diet formulation. Corrected Energy levels for the DDGS 15% and DDGS 30% test diets were lower than formulated ME levels (99.8 and 97.9%, respectively); the Corrected Energy of the CGM test diet was greater than formulated levels (101.2%). The Energy Difference of the test diet was calculated as the difference between formulated ME level and the Corrected Energy level of the test diet. This difference was relatively small for the DDGS 15% diet (+7 kcal/kg) but larger for the DDGS 30% diet (+73 kcal/kg) and the CGM diet (-42 kcal/kg; Table 3.9).

The Energy Difference of the test diet was assumed to be due entirely to an inaccurate estimate of the energy value of the test ingredient that was used in diet formulation. Therefore, the next step was to calculate the Energy Difference of the Test Ingredient, which was calculated by dividing the Energy Difference of the Test Diet by the proportion of test ingredient in the diet (Table 3.9), which resulted in values for the Energy Difference of the Test Ingredient of -47, -243, and +221 kcal/kg for the DDGS 15%, DDGS 30%, and CGM, respectively.

The PME of the ingredients was calculated by subtracting the Energy Difference of the Test Ingredient from the Formulated Energy of the Test Ingredient. This resulted in estimates of PME of 2,956, 2,760, and 2,800 kcal/kg for the DGGS at 15% inclusion, DDGS at 30% inclusion, and CGM, respectively. The PME values for DDGS represent 98% and 91.9% of the original ME value used in diet formulation based on the DDGS 15% and DDGS 30% treatments, respectively, and 108.6% of the original ME value of CGM used in diet formulation.

The only other studies to estimate the PME of CGM using growth assays were those of Estrada (2017) who conducted two experiments to estimate PME that had a similar experimental design as the current study. The first study by Estrada (2017) had 2 CGM inclusion level treatments (12.5 and 25%) and the second had 4 CGM inclusion levels (10, 20, 30, 40%). The estimate of PME of CGM was 2,604 kcal/kg for both inclusion levels in the first study and ranged between 2,397 to 2,519 kcal/kg in the second study. The results from the two studies by

Estrada (2017) highlight the considerable variation in estimates of PME of CGM among studies, and also depending on the conditions used to derive the estimates.

There have been no published studies estimating the PME of DDGS. Therefore, the only comparison that can be made was with published ME values that have been summarized in NRC (2012). In the current study, the estimates of the PME content of DDGS included at 15% and DDGS included at 30% were 2,956 and 2,760 kcal/kg, respectively, which are substantially lower than the ME values in NRC (2012) that ranged between 3,476 and 3,845 kcal/kg. The reason for this relatively large difference in ME values could be due, in part at least, to the methods used to obtain these values. The estimation of PME is based on feed efficiency measured in a growth study, whereas, and the estimates of ME in NRC (2012) are obtained from digestibility studies that involve direct measurement of the energy content of feed, feces, and urine. One of the objectives of the current study was to provide estimates of the PME content of DDGS that could be used in diet formulation. The estimate of the PME varied considerably depending on the inclusion level of DDGS in the test diet with the difference being 196 kcal/kg or 6.6% of the estimate based on the 15% DDGS inclusion level. Estrada (2017) also found considerable variation in the PME estimates for CGM depending on the conditions under which the study was conducted. In particular, Estrada (2017) carried out two studies to test the impact of CGM dietary inclusion level on estimates of the PME of CGM. In the first study, there was no difference in the PME estimates based on feeding diets with either 12.5% or 25% CGM inclusion level. However, in the second study there was considerable variation in PME estimates based on feeding diets containing between 10 % and 40 % CGM which at the extreme amounted to 122 kcal/kg or approximately 5% of the estimate based on the diets with 10% CGM inclusion. A possible explanation for the differences in estimates of PME in this study and those in the studies of Estrada (2017) is the weight of pigs used which differed between the studies. The digestibility of fiber in smaller animals is not as extensive as in larger pigs due to the smaller hindgut size and an increase in rate of passage of fiber rich diets through the digestive tract (Noblet and van Milgen, 2004). Differences in fiber digestibility will result in differences in PME estimates.

Another reason for differences in PME estimates between studies would be differences in the composition of the sample being evaluated. The DDGS sample used in this study had a lower lysine level than normal (Table 3.2). This lower lysine level could have resulted in a lysine deficiency in the DDGS diets, particularly at the 30% inclusion level which would have affected growth performance and, consequently, the PME estimate obtained.

The other factor that could have contributed the variation in PME estimates between the 2 DDGS levels is uncertainty over the energy value of the fat source used. There is large variation in types of and sources of fat, which leads to variation of the energy content. Fat was included at different levels in the diets used in this study and the use of an inaccurate value for energy content in diet formulation could have resulted in actual dietary energy levels varying from formulated values. This would produce variation between diets in PME estimates.

The estimate of the PME content of CGM obtained in the current study was 2,800 kcal/kg, which is greater than the values obtained in the studies of Estrada (2017) that ranged between 2,397 and 2,604 kcal/kg. The reason(s) for this relatively large difference in the energy value of CGM obtained in the current study compared to the studies of Estrada (2017) is not apparent. All of these studies were carried out in the same production facility and used similar methodology. Different samples of CGM were used in the current study and the two studies of Estrada (2017), which may have resulted in some variation in estimates of PME. The nutrient content of the sample of CGM used in this study was generally lower than that used by Estrada (2017) and this could have contributed to the variation in the estimate of PME observed between studies.

The estimation of PME starts with the results for feed efficiency and, therefore, any factor that affects the accuracy of measurement of feed efficiency contributed to variation in the estimates of productive energy. Feed wastage is a major factor influencing feed efficiency and contributes to variation in PME estimates. In actual fact, it is feed disappearance and not actual feed that was measured. In practice, not all of the feed that is delivered to the pens is consumed by the pigs, with some being wasted. Differences in feed wastage between dietary treatments would contribute to variation in PME estimates. However, in the current study and in those of Estrada (2017) considerable efforts were made to keep feeder settings adjusted to minimize feed wastage and there was no evidence that wastage varied between the various dietary treatments.

In conclusion, the estimates of PME of DDGS obtained in this study varied considerably depending on dietary inclusion level and were also substantially lower than ME values published in NRC (2012). In addition, the estimate of the PME content of CGM was significantly greater than estimates of PME obtained by Estrada (2017) in studies carried out in the same facilities and using similar methodology as in the present study.

CONCLUSIONS

The results of this research suggest no effect of including either 15% DDGS or 20% CGM in diets for growing-finishing pigs on growth performance and carcass characteristics when the energy content of the diets is balanced with fat; however, including 30% DDGS resulted in a reduction in feed efficiency. The estimate of the PME content of CGM was substantially different from the estimates of PME of this ingredient obtained by Estrada (2017) in studies carried in the same facilities and using similar methodology as the current study. In addition, the estimates of the PME of DDGS differed substantially depending on the dietary inclusion level of this ingredient. Collectively, these results raise questions about the accuracy of estimates of PME derived from growth studies. Further research is needed to determine the reason(s) for this wide variation in estimates of productive energy within and between studies.

TABLES

Table 3.1 Dietary phases and feed budget for the experiment.

	Barrows		Gilts	
Dietary Phase[1]	Feed/pig (kg)	Live Weight Range (kg)	Feed/pig (kg)	Live Weight Range (kg)
GF-1	64.4	40.8-68.0	60.8	40.8-68.0
GF-2	49.0	68.5-86.6/90.7	48.5	68.5-86.6/90.7
PF 010	55.3	87.1/91.2-104.3	51.7	87.1/91.2-104.3
PF 011	88.9	104.3-129.3	81.2	104.3-129.3

[1]All diets were fed in pellet form.

Table 3.2. Analyzed composition of corn, soybean meal (SBM), distiller's dried grains with solubles (DDGS) and corn germ meal (CGM) used to manufacture experimental diets.

Item	Corn	SBM[1]	DDGS[2]	CGM[1]
Proximate analysis, % as-fed basis[3]				
Dry matter	-	88.49	-	-
Crude protein	7.68	46.79	29.9	23.03
Crude fat	3.30	1.26	5.31	2.17
Crude fiber	1.31	2.95	4.07	7.34
Acid detergent fiber	2.03	5.84	12.20	11.93
Neutral detergent fiber	7.03	7.39	28.30	37.20
Phosphorus	0.29	0.72	1.06	0.76
Calcium	0.00	0.53	0.04	0.02
Sodium	-	-	0.27	0.04
Ash	1.15	5.83	4.69	2.47
Chloride	-	-	0.18	0.05
Amino acid analysis, % as-fed basis[4]				
Alanine	-	1.95	1.86	1.27
Arginine	-	3.20	1.16	1.44
Aspartic acid	-	5.09	1.69	1.50
Cystine	-	0.61	0.51	0.30
Glutamic acid	-	8.03	4.48	2.82
Glycine	-	1.88	1.11	1.16
Histidine	-	1.13	0.66	0.58
Isoleucine	-	1.98	1.01	0.72
Leucine	-	3.39	2.90	1.57
Lysine	-	2.73	0.74	0.83
Methionine	-	0.61	0.50	0.38
Methionine + Cystine	-	1.23	1.00	0.68
Phenylalanine	-	2.36	1.26	0.93
Proline	-	2.31	1.91	1.00
Serine	-	2.25	1.25	0.99
Threonine	-	1.75	0.94	0.79
Tryptophan	-	0.66	0.23	0.26
Tyrosine	-	1.40	0.89	0.52
Valine	-	2.03	1.23	1.09

[1]SBM and CGM origin: Archer Daniels Midland, Decatur, IL.
[2]DDGS origin: Center Ethanol, Sauget, IL.
[3]Proximate analysis was performed at Midwest Laboratories, Omaha, NE.
[4]Amino acid analysis was performed using High-Performance Liquid Chromatography (HPLC), Ajinomoto Heartland, LLC, Chicago, IL.

Table 3.3 Diet formulation and calculated and analyzed nutrient values for grow-finish 1 diets.

		Treatments							
Ingredient Name, kg		Control		DDGS 15%		DDGS 30%		Corn Germ Meal	
Corn-fine, Carlyle, IL		667.89		554.88		441.86		508.75	
Corn germ meal		-		-		-		177.36	
DDGS, Sauget		-		136.08		272.16		-	
Soybean meal, ADM, Decatur, IL		208.29		178.22		148.14		153.58	
Fat-yellow grease pelleter		-		10.91		21.82		36.96	
Limestone		8.86		10.38		11.89		10.17	
Fat-yellow grease		5.26		4.90		4.54		4.54	
Salt		4.13		2.69		1.24		4.15	
Monocalcium phosphate (21%)		5.96		2.98		-		3.93	
Lysine, dry (98%)		2.94		3.28		3.63		3.63	
Alimet		1.04		0.52		-		1.18	
Threonine (98%)		0.88		0.50		0.11		0.95	
Trace mineral		0.68		0.68		0.68		0.68	
Mycotoxin Binder		0.45		0.45		0.45		0.45	
Vitamin premix		0.27		0.27		0.27		0.27	
Copper chloride (54%)		0.25		0.25		0.25		0.25	
Phytase 2500 GT 500FTU/Kg		0.29		0.15		-		0.39	
Skycis 100		0.30		0.30		0.30		0.30	
		1000		1000		1000		1000	
Nutrient Name	Units	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
ME -Swine	Kcal/kg	3395	-	3395	-	3395	-	3395	-
Crude Protein	%	16.24	16.90	18.20	18.80	20.17	20.40	16.78	16.70
Crude Fat	%	3.08	3.97	4.75	5.54	6.42	6.57	6.72	6.72
Crude Fiber	%	1.62	1.20	2.23	1.55	2.84	2.31	2.75	2.19
ADF	%	2.54	2.90	4.21	4.10	5.88	5.60	4.29	4.60
NDF	%	6.20	6.80	9.03	9.80	11.87	11.70	12.00	13.20
Ash	%	3.67	4.08	3.88	4.43	4.09	4.65	3.52	4.03
Moisture	%	12.65	12.07	12.19	11.84	11.74	11.60	11.81	11.33
Phosphorus	%	0.48	0.53	0.49	0.53	0.50	0.54	0.48	0.48
P, Available	%	0.24	-	0.24	-	0.25	-	0.24	-
Calcium	%	0.58	0.67	0.58	0.64	0.58	0.76	0.58	0.82
Calcium:Phosphorus		1.20	-	1.18	-	1.15	-	1.20	-
Sodium	%	0.20	0.22	0.20	0.20	0.20	0.18	0.20	0.19

Table 3.3 (Cont.)

Chloride	%	0.39	0.39	0.32	0.35	0.25	0.32	0.40	0.36
Magnesium	%	0.18	0.16	0.21	0.18	0.23	0.20	0.18	0.14
Potassium	%	0.73	0.78	0.78	0.84	0.84	0.88	0.62	0.61
Copper	ppm	170.93	206.00	170.80	194.00	170.67	187.00	170.43	177.00
Iodine	ppm	0.22	-	0.22	-	0.22	-	0.22	-
Iron	ppm	221.38	267.00	231.71	229.00	242.05	204.00	232.20	246.00
Manganese	ppm	43.93	60.60	45.02	48.80	46.12	45.80	43.33	45.20
SE, Added	ppm	0.22	-	0.22	-	0.22	-	0.22	-
Zinc	ppm	149.82	211.00	155.51	187.00	161.21	177.00	160.77	155.00
Lysine, Total	%	1.05	1.11	1.09	1.09	1.13	1.10	1.08	1.10
Lysine, Dig	%	0.94	-	0.94	-	0.94	-	0.94	-
Isoleucine, Total	%	0.64	0.65	0.70	0.69	0.76	0.73	0.63	0.66
Isoleucine, Dig	%	0.56	-	0.59	-	0.63	-	0.53	-
Leucine, Total	%	1.43	1.52	1.70	1.71	1.96	1.92	1.40	1.52
Leucine, Dig	%	1.25	-	1.46	-	1.68	-	1.20	-
Met + Cys, Total	%	0.61	0.54	0.66	0.62	0.70	0.67	0.63	0.56
Met + Cys, Dig	%	0.54	-	0.55	-	0.57	-	0.54	-
Threonine, Total	%	0.69	0.73	0.72	0.74	0.75	0.75	0.71	0.74
Threonine, Dig	%	0.59	-	0.59	-	0.59	-	0.59	-
Tryptophan, Total	%	0.19	0.19	0.20	0.21	0.20	0.20	0.19	0.19
Tryptophan, Dig	%	0.17	-	0.17	-	0.17	-	0.17	-
Valine, Total	%	0.72	0.73	0.82	0.79	0.91	0.86	0.77	0.78
Valine, Dig	%	0.61	-	0.67	-	0.74	-	0.63	-

Table 3.4 Diet formulation and calculated and analyzed nutrient values grow-finish 2 diets.

	Treatments			
Ingredient Name, kg	Control	DDGS 15%	DDGS 30%	Corn Germ Meal
Corn-fine, Carlyle, IL	723.24	606.44	489.63	566.26
Corn germ meal	-	-	-	172.84
DDGS, Sauget	-	136.08	272.16	-
Soybean meal, ADM, Decatur, IL	155.46	126.51	97.57	104.88
Fat-yellow grease pelleter	3.18	14.73	26.29	38.38
Limestone	7.98	8.93	9.87	8.54
Fat-yellow grease	4.54	4.54	4.54	4.54
Salt	4.59	3.51	2.42	4.15
Lysine, dry (98%)	2.33	2.65	2.97	2.92
Monocalcium phosphate (21%)	2.89	1.45	-	1.57
Trace mineral	0.68	0.68	0.68	0.68
Threonine (98%)	0.59	0.30	-	0.63
Alimet	0.45	0.23	-	0.54
Mycotoxin Binder	0.45	0.45	0.45	0.45
Copper chloride (54%)	0.25	0.25	0.25	0.25
Vitamin premix	0.23	0.23	0.23	0.23
Phytase 2500 GT 500FTU/Kg	0.40	0.20	-	0.40
Skycis 100	0.30	0.30	0.30	0.30
	1000	1000	1000	1000

Nutrient Name	Units	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
ME -Swine	Kcal/kg	3428	-	3428	-	3428	-	3428	-
Crude Protein	%	13.85	14.40	15.86	15.90	17.88	18.00	14.49	15.30
Crude Fat	%	3.47	4.58	5.24	5.66	7.01	7.74	7.00	6.97
Crude Fiber	%	1.51	1.09	2.12	1.28	2.73	1.80	2.61	1.54
ADF	%	2.35	2.30	4.01	3.60	5.68	6.50	4.06	5.00
NDF	%	6.14	7.00	8.96	9.30	11.77	12.00	11.80	12.00
Ash	%	2.97	3.61	3.29	3.81	3.61	4.16	2.83	3.41
Moisture	%	12.77	12.77	12.28	12.41	11.80	11.66	11.96	12.13
Phosphorus	%	0.39	0.39	0.43	0.43	0.48	0.50	0.41	0.41
P, Available	%	0.18	-	0.21	-	0.24	-	0.18	-
Calcium	%	0.47	0.53	0.47	0.53	0.48	0.53	0.45	0.51
Calcium:phosphorus		1.20	-	1.09	-	1.00	-	1.11	-
Sodium	%	0.22	0.20	0.21	0.24	0.20	0.22	0.20	0.20
Chloride	%	0.40	0.41	0.36	0.36	0.31	0.32	0.38	0.43
Magnesium	%	0.17	0.13	0.19	0.14	0.22	0.18	0.16	0.13

Table 3.4 (Cont.)

Potassium	%	0.62	0.67	0.68	0.72	0.74	0.79	0.52	0.59
Copper	ppm	169.97	183.00	169.85	185.00	169.74	178.00	169.54	185.00
Iodine	ppm	0.22	-	0.22	-	0.22	-	0.22	-
Iron	ppm	208.91	196.00	217.22	212.00	225.53	221.00	217.14	216.00
Manganese	ppm	41.90	47.90	42.89	51.20	43.89	51.20	41.26	43.10
SE, Added	ppm	0.22	-	0.22	-	0.22	-	0.22	-
Zinc	ppm	147.63	146.00	153.32	161.00	159.01	166.00	158.42	158.00
Lysine, Total	%	0.86	0.87	0.89	0.88	0.93	0.84	0.88	0.91
Lysine, Dig	%	0.76	-	0.76	-	0.76	-	0.76	-
Isoleucine, Total	%	0.54	0.52	0.60	0.60	0.67	0.68	0.53	0.53
Isoleucine, Dig	%	0.46	-	0.50	-	0.54	-	0.45	-
Leucine, Total	%	1.29	1.29	1.56	1.48	1.82	1.74	1.27	1.30
Leucine, Dig	%	1.12	-	1.34	-	1.55	-	1.08	-
Met + Cys, Total	%	0.50	0.48	0.58	0.53	0.65	0.61	0.52	0.49
Met + Cys, Dig	%	0.43	-	0.48	-	0.52	-	0.43	-
Threonine, Total	%	0.57	0.59	0.61	0.62	0.65	0.62	0.59	0.63
Threonine, Dig	%	0.48	-	0.49	-	0.50	-	0.48	-
Tryptophan, Total	%	0.16	0.15	0.16	0.16	0.17	0.16	0.16	0.19
Tryptophan, Dig	%	0.14	-	0.14	-	0.14	-	0.14	-
Valine, Total	%	0.63	0.61	0.72	0.68	0.82	0.77	0.68	0.68
Valine, Dig	%	0.53	-	0.59	-	0.65	-	0.55	-

Table 3.5 Diet formulation and calculated and analyzed nutrient values grow-finish 3 diets.

		Treatments							
Ingredient Name, kg		Control		DDGS 15%		DDGS 30%		Corn Germ Meal	
Corn-fine, Carlyle, IL		749.94		632.85		515.77		595.74	
Corn germ meal		-		-		-		169.85	
DDGS, Sauget		-		136.08		272.16			
Soybean meal, ADM, Decatur, IL		133.33		104.39		75.45		83.57	
Fat-yellow grease pelleter		-		11.56		23.12		34.52	
Limestone		7.85		8.84		9.82		9.12	
Fat-yellow grease		4.54		4.54		4.54		4.54	
Salt		4.13		3.05		1.96		3.69	
Lysine, dry (98%)		2.15		2.47		2.79		2.74	
Monocalcium phosphate (21%)		2.66		1.33		-		0.65	
Threonine (98%)		0.54		0.27		-		0.57	
Trace mineral		0.57		0.57		0.57		0.57	
Mycotoxin Binder		0.45		0.45		0.45		0.45	
Alimet		0.23		0.11		-		0.32	
Copper chloride (54%)		0.25		0.25		0.25		0.25	
Vitamin premix		0.18		0.18		0.18		0.18	
Phytase 2500 GT 500FTU/Kg		0.52		0.26		-		0.64	
Skycis 100		0.30		0.30		0.30		0.30	
		1000		1000		1000		1000	
Nutrient Name	Units	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
ME -Swine	Kcal/kg	3417	-	3417	-	3417	-	3417	-
Crude Protein	%	12.89	12.00	14.91	14.90	16.94	17.40	13.52	13.80
Crude Fat	%	3.19	3.62	4.96	4.53	6.73	5.27	6.65	6.80
Crude Fiber	%	1.47	1.30	2.07	1.56	2.68	2.16	2.55	1.62
ADF	%	2.27	2.70	3.94	4.30	5.60	6.10	3.96	4.70
NDF	%	6.14	7.80	8.95	10.20	11.77	13.80	11.70	12.60
Ash	%	2.82	3.28	3.16	3.52	3.49	3.97	2.69	3.01
Moisture	%	12.87	13.48	12.39	13.15	11.90	12.10	12.08	12.27
Phosphorus	%	0.38	0.38	0.42	0.45	0.47	0.50	0.38	0.34
P, Available	%	0.18	-	0.21	-	0.24	-	0.18	-
Calcium	%	0.45	0.64	0.46	0.56	0.47	0.55	0.45	0.53
Calcium:phosphorus		1.20	-	1.09	-	1.00	-	1.20	-
Sodium	%	0.20	0.18	0.19	0.19	0.18	0.19	0.18	0.14

Table 3.5 (Cont.)

Chloride	%	0.37	0.34	0.32	0.32	0.28	0.28	0.35	0.30
Magnesium	%	0.16	0.12	0.19	0.15	0.22	0.18	0.16	0.11
Potassium	%	0.58	0.57	0.64	0.68	0.69	0.76	0.48	0.46
Copper	ppm	167.48	178.00	167.36	186.00	167.24	178.00	167.06	164.00
Iodine	ppm	0.19	-	0.19	-	0.19	-	0.19	-
Iron	ppm	182.47	210.00	190.93	237.00	199.39	228.00	193.31	139.00
Manganese	ppm	36.03	46.40	37.03	56.70	38.04	42.00	35.56	32.80
SE, Added	ppm	0.19	-	0.19	-	0.19	-	0.19	-
Zinc	ppm	125.93	123.00	131.62	152.00	137.30	142.00	136.54	147.00
Lysine, Total	%	0.78	0.77	0.82	0.80	0.85	0.78	0.81	0.79
Lysine, Dig	%	0.69	-	0.69	-	0.69	-	0.69	-
Isoleucine, Total	%	0.50	0.49	0.56	0.56	0.63	0.63	0.49	0.48
Isoleucine, Dig	%	0.43	-	0.47	-	0.51	-	0.41	-
Leucine, Total	%	1.23	1.21	1.50	1.45	1.76	1.67	1.21	1.20
Leucine, Dig	%	1.07	-	1.29	-	1.50	-	1.03	-
Met + Cys, Total	%	0.46	0.44	0.54	0.52	0.63	0.58	0.48	0.45
Met + Cys, Dig	%	0.39	-	0.45	-	0.50	-	0.39	-
Threonine, Total	%	0.53	0.52	0.57	0.57	0.62	0.60	0.55	0.57
Threonine, Dig	%	0.44	-	0.45	-	0.47	-	0.44	-
Tryptophan, Total	%	0.14	0.14	0.15	0.15	0.16	0.16	0.15	0.15
Tryptophan, Dig	%	0.12	-	0.12	-	0.12	-	0.12	-
Valine, Total	%	0.59	0.57	0.68	0.66	0.78	0.73	0.64	0.61
Valine, Dig	%	0.49	-	0.55	-	0.62	-	0.51	-

Table 3.6 Diet formulation and calculated and analyzed nutrient values grow-finish 4 diets.

	Treatments			
Ingredient Name, kg	Control	DDGS 15%	DDGS 30%	Corn Germ Meal
Corn-fine, Carlyle, IL	663.73	535.11	406.49	489.23
DDGS, Sauget	-	136.08	272.16	-
Soybean meal, ADM, Decatur, IL	216.69	198.86	181.04	186.34
Corn germ meal	-	-	-	171.60
Fat-yellow grease pelleter	-	12.27	24.54	34.97
Limestone	8.16	9.19	10.22	8.64
Fat-yellow grease	6.35	6.35	6.35	6.35
Salt	4.13	3.20	2.27	3.69
Lysine, dry (98%)	2.72	2.72	2.71	2.72
Alimet	1.00	0.50	-	0.91
Threonine (98%)	0.95	0.48	-	0.71
Trace mineral	0.57	0.57	0.57	0.57
Ractopamine HCL (10g/lb)	0.34	0.34	0.34	0.34
Monocalcium phosphate (21%)	1.68	0.84	-	0.26
Copper chloride (54%)	0.25	0.25	0.25	0.25
Vitamin premix	0.18	0.18	0.18	0.18
Phytase 2500 GT 500FTU/Kg	0.80	0.40	0.00	0.80
Zinc Oxide (72%)	0.15	0.15	0.15	0.15
	1000	1000	1000	1000

Nutrient Name	Units	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed	Calculated	Analyzed
ME -Swine	Kcal/kg	3419	-	3419	-	3419	-	3419	-
Crude Protein	%	16.61	16.50	19.04	19.50	21.47	20.80	18.03	18.30
Crude Fat	%	3.20	3.90	5.01	5.41	6.83	7.16	6.67	6.20
Crude Fiber	%	1.65	1.41	2.28	2.20	2.91	2.52	2.79	2.43
ADF	%	2.58	2.90	4.29	6.50	5.99	6.70	4.36	4.20
NDF	%	6.24	7.80	9.07	10.80	11.90	13.00	11.90	12.80
Ash	%	3.17	3.70	3.62	4.46	4.07	4.34	3.11	3.77
Moisture	%	12.67	13.10	12.15	12.49	11.63	11.57	11.84	12.32
Phosphorus	%	0.39	0.40	0.45	0.46	0.52	0.53	0.41	0.42
P, Available	%	0.20	-	0.22	-	0.25	-	0.20	-
Calcium	%	0.47	0.56	0.49	0.60	0.52	0.64	0.45	0.58
Calcium:Phosphorus		1.20	-	1.09	-	1.00	-	1.09	-
Sodium	%	0.20	0.21	0.20	0.18	0.19	0.17	0.18	0.18
Chloride	%	0.38	0.41	0.34	0.34	0.30	0.28	0.35	0.36
Magnesium	%	0.18	0.14	0.21	0.16	0.24	0.19	0.18	0.14

Table 3.6 (Cont.)

Potassium	%	0.75	0.77	0.83	0.87	0.91	0.96	0.69	0.74
Copper	ppm	168.99	191.00	169.08	181.00	169.16	180.00	168.94	192.00
Iodine	ppm	0.19	-	0.19	-	0.19	-	0.19	-
Iron	ppm	198.11	181.00	208.69	180.00	219.27	186.00	209.44	200.00
Manganese	ppm	39.00	16.70	40.40	38.70	41.80	39.90	39.04	50.50
SE, Added	ppm	0.19	-	0.19	-	0.19	-	0.19	-
Zinc	ppm	183.42	219.00	189.57	200.00	195.72	199.00	195.00	204.00
Lysine, Total	%	1.06	1.08	1.10	1.07	1.14	1.10	1.09	1.13
Lysine, Dig	%	0.95	-	0.95	-	0.95	-	0.95	-
Isoleucine, Total	%	0.65	0.68	0.74	0.74	0.83	0.82	0.69	0.73
Isoleucine, Dig	%	0.57	-	0.63	-	0.69	-	0.59	-
Leucine, Total	%	1.46	1.49	1.76	1.80	2.05	2.02	1.49	1.54
Leucine, Dig	%	1.27	-	1.52	-	1.76	-	1.28	-
Met + Cys, Total	%	0.62	0.54	0.67	0.65	0.73	0.71	0.64	0.56
Met + Cys, Dig	%	0.54	-	0.57	-	0.60	-	0.54	-
Threonine, Total	%	0.71	0.71	0.75	0.76	0.79	0.80	0.73	0.76
Threonine, Dig	%	0.61	-	0.61	-	0.62	-	0.61	-
Tryptophan, Total	%	0.20	0.20	0.21	0.22	0.22	0.22	0.21	0.22
Tryptophan, Dig	%	0.17	-	0.18	-	0.19	-	0.18	-
Valine, Total	%	0.74	0.74	0.86	0.83	0.97	0.92	0.83	0.83
Valine, Dig	%	0.63	-	0.71	-	0.79	-	0.69	-

Table 3.7 Least-squares means for the effect of dietary inclusion of distillers dried grains with solubles and corn germ meal on pig growth performance during the grow-finish period.

	Treatments[1,2]					
	Control	DDGS 15%	DDGS 30%	Corn Germ Meal	SEM	*P*-value
Number of pens, n	24	24	24	24	-	-
Live weight, kg						
Start of test[3]	48.2	48.2	48.2	48.2	0.68	0.83
Week 2	63.5	63.2	62.6	62.9	0.49	0.08
Week 4	77.2[a]	76.9[ab]	75.5[c]	76.4[b]	0.52	<0.001
Week 6	90.1[a]	89.8[a]	88.5[b]	89.5[a]	0.47	0.01
Week 8	107.6	107.8	107.7	107.1	0.45	0.64
Week 10	125.2	125.6	124.9	124.8	0.46	0.60
End of test	132.4	132.9	132.4	132.1	0.69	0.77
Days on test[4]	83.0	84.5	84.9	84.3	0.88	0.25
Average daily gain, kg						
Start - week 2	0.98[a]	0.97[a]	0.92[b]	0.94[ab]	0.017	0.05
Week 2 - Week 4	1.03[a]	1.02[a]	0.98[b]	1.01[ab]	0.020	0.04
Week 4 - Week 6	1.08	1.07	1.08	1.11	0.018	0.31
Week 6 - Week 8	1.14	1.14	1.15	1.14	0.015	0.91
Week 8 - Week 10	1.25	1.26	1.23	1.27	0.015	0.42
Week 10 - Week 12	1.09	1.11	1.11	1.10	0.025	0.92
Overall (live weight)	1.09	1.09	1.08	1.09	0.008	0.08
Overall (carcass)[5]	0.83[a]	0.82[a]	0.80[b]	0.82[a]	0.008	0.02
Average daily feed intake, kg						
Start - Week 2	1.94[a]	1.92[a]	1.89[ab]	1.86[b]	0.024	0.02
Week 2 - week 4	2.35[a]	2.32[a]	2.30[ab]	2.25[b]	0.031	0.01
Week 4 - Week 6	2.57	2.59	2.61	2.61	0.037	0.55
Week 6 - Week 8	2.98[b]	2.98[b]	3.04[a]	2.95[b]	0.038	0.01
Week 8 - Week 10	3.01	2.99	3.00	2.96	0.027	0.14
Week 10 - Week 12	3.20	3.22	3.23	3.17	0.055	0.57
Overall	2.62[a]	2.61[a]	2.63[a]	2.58[b]	0.026	0.01
Gain:Feed, kg:kg						
Start - Week 2	0.508[a]	0.502[ab]	0.486[b]	0.507[a]	0.0062	0.04
Week 2 - week 4	0.438[a]	0.438[a]	0.425[b]	0.449[a]	0.0056	0.004
Week 4 - Week 6	0.418	0.414	0.416	0.423	0.0059	0.35
Week 6 - Week 8	0.384	0.384	0.380	0.389	0.0041	0.32
Week 8 - Week 10	0.416[ab]	0.423[ab]	0.411[b]	0.428[a]	0.0054	0.04
Week 10 - Week 12	0.339	0.346	0.342	0.349	0.0063	0.64
Overall (live weight)	0.419[b]	0.418[b]	0.410[c]	0.424[a]	0.0027	<0.001
Overall (carcass)[6]	0.315[a]	0.314[a]	0.306[b]	0.318[a]	0.0022	<0.001

[a,b,c] Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Control = Corn and soybean meal; DDGS 15% = Control + 15% DDGS inclusion level; DDGS 30% = Control + 30% DDGS inclusion level; Corn Germ Meal = Control formulated to the same NDF level as DDGS 30% with ~19% inclusion of corn germ meal..

[2]4 Dietary phases were fed. Grow-Finish 1- fed from start of test to Week 2; Grow-Finish 2 was fed from Week 2 to Week 6; Grow-Finish 3- was fed from Week 6 to Week 8; Grow-Finish 4 (Ractopamine added) was fed from Week 8 to Week 12.

[3]Pigs were approximately 10 weeks post-weaning at the start of test.

[4]Days on test = days from start of test to removal of harvest group 2.

[5]Carcass average daily gain = overall average daily gain × carcass yield.

[6]Carcass gain:feed = carcass average daily gain / overall average daily feed intake.

Table 3.8 Least-squares means for effects of dietary inclusion of distillers dried grains with solubles and corn germ meal on carcass characteristics.

	Treatments[1]					
	Control	DDGS 15%	DDGS 30%	Corn Germ Meal	SEM	*P*-value
Harvest live weight, kg	133.2	133.5	132.7	132.7	0.48	0.35
Hot carcass weight, kg	101.0[a]	100.6[a]	99.3[b]	99.6[b]	0.39	0.003
Carcass yield, %	75.5	75.0	74.8	74.8	0.31	0.23
Backfat depth, mm[2]	16.26	15.82	15.82	15.90	0.292	0.15
Longissimus muscle depth, cm^2	6.83[a]	6.63[b]	6.49[b]	6.62[b]	0.0615	<0.001

[a,b,c] Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Control = Corn and soybean meal; DDGS (15% NDF) = Control with 15% NDF from DDGS; DDGS (30% NDF) = Control + 30% NDF from DDGS; CGM = Control + 20% NDF from corn germ meal.

[2]Measured using a Fat-O-Meater at approximately the 10^{th} rib.

Table 3.9 Calculation of the Productive ME of Distillers Dried Grains with Solubles (DDGS) and Corn Germ Meal (CGM).

	Control	Distillers Dried Grains with Solubles level, %		Corn germ meal level, %
Item	-	15	30	19
Formulated Energy Content, (kcal/kg)[1]:				
Dietary ME[7]	3,415	3,415	3,415	3,415
Corn Germ Meal ME[8]		-	-	2,579
Distillers Dried Grains with Solubles ME[9]		3,003	3,003	-
Calculations:				
1) Caloric Efficiency[2], kcal/kg	8,151	8,169	8,329	8,053
2) Corrected Energy of Test Diet[3], kcal/kg		3,408	3,342	3,457
3) Energy Difference of Test Diet[4], kcal		7	73	-42
4) Energy Difference of Test Ingredient[5], kcal/kg		47	243	-221
5) Productive ME of DDGS and CGM[6], kcal/kg		2,956	2,760	2,800
6) Productive Energy of DDGS and CGM relative to Energy of Corn, %[10]		88%	82%	83%

[a,b,c]Means with different superscripts within experiment are different ($P \leq 0.05$).

[1]As-fed basis.

[2]Caloric Efficiency (CE), kcal/kg of gain = Feed:Gain × (Formulated Energy of the Diet, kcal/kg).

[3]Corrected Energy of Test Diet, kcal/kg = Formulated Energy of Test Diet × (CE of Control diet ÷ CE of Test Diet).

[4]Energy Difference of Test Diet = Formulated Energy of Test Diet - Corrected Energy of Test Diet.

[5]Energy Difference of Test Ingredient (i.e., CGM) = Energy Difference of Test Diet ÷ Proportion of Test Ingredient in the Diet.

[6]Productive Energy, kcal/kg = Formulated Energy of Test Ingredient - Energy Difference of Test Ingredient.

[7]Dietary ME = ME of formulated diets.

[8]Corn Germ Meal ME = Energy estimate of corn germ meal from NRC (2012) and Estrada (2017).

[9]Distillers Dried Grains with Solubles ME = Energy estimate of distillers dried grains with solubles from NRC (2012).

[10]Productive Energy of DDGS and CGM Relative to Energy of Corn, % = Energy Difference of Test Ingredient ÷ (Energy of Corn × 2.2046).

LITERATURE CITED

Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 89:4109-4115.

Anderson, P. V., B. J. Kerr, T. E. Weber, C. J. Ziemer, and G. C. Shurson. 2012. Determination and prediction of digestible and metabolizable energy from chemical analysis of corn coproducts fed to finishing pigs. J. Anim. Sci. 90:1242–1254.

Estrada, J. R. 2017. Effects of body weight and research conditions on the productive energy content of corn germ meal fed to growing-finishing pigs. PhD Diss. Univerity of Illinois, Urbana-Champaign.

Gutierrez, N. A., N. V. L. Serão, B. J. Kerr, R. T. Zijlstra, and J. F. Patience. 2014. Relationships among dietary fiber components and the digestibility of energy, dietary fiber, and amino acids and energy content of nine corn coproducts fed to growing pigs. J. Anim. Sci. 92:4505-4517.

Jones, R. W. 1987. Corn co-products as feed ingredients for swine: Effects on growth, carcass composition and fiber and amino acid digestibility. PhD Diss. University of Illinois at Urbana-Champaign.

Kil, D. Y., B. G. Kim, and H. H. Stein. 2013. Invited review: Feed energy evaluation for growing pigs. Asian-Australas. J. Anim. Sci. 26:1205-1217.

Mendoza, Omarh. 2013. Development and valdiation of prediction equations for the metabolizable energy content of distillers dried grains with solubles from different sources for pigs. PhD Diss. Univerity of Illinois, Urbana-Champaign.

Noblet, J., and J. van Milgen. 2004. Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J. Anim. Sci. 82 (E. Suppl.): E229-E238.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

Stein, H. H., and G. C. Shurson. 2009. Board-Invited Review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.